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THE STUDY OF THE GLACIAL STRATIGRAPHY AND SEDIMENTATION OF THE SHELDON POINT MORAINE, SAINT JOHN, NEW BRUNSWICK

Linda P. Nicks

Natural Resources and Energy

Mineral Resources

ISSN 1183-5508

Price $4.90

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December, 1991

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92-01922/

This report should be referenced in the following manner:

NICKS, L.P. 1991. The study of the glacial stratigraphy and sedimentation of the Sheldon Point Moraine, Saint John, New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Open File Report 91-12, 171 p.

The Study of the Glacial Stratigraphy and Sedimentation of the Sheldon Point Moraine, Saint John, New Brunswick

by

Linda P. Nicks

Submitted in partial fulfillment of the requirements for
the degree of Master of Science
at
Dalhousie University
Halifax, Nova Scotia
September, 1988

DALHOUSIE UNIVERSITY

DEPARTMENT OF GEOLOGY

The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "The Study of the glacial stratigraphy and sedimentation of the Sheldon Point Moraine, Saint John, New Brunswick" by Linda P. Nicks in partial fulfillment of the requirements for the degree of Master of Science.

MINERALS AND ENERGY DIVISION
DEPARTMENT OF NATURAL RESOURCES AND ENERGY
NEW BRUNSWICK

DATE June 6/91

AUTHOR Linda P. Nicks

TITLE The Study of the Glacial Stratigraphy and Sedimentation of the Sheldon Point Moraine, Saint John, New Brunswick

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I would like to dedicate this thesis to my parents Maurice and Dorothy Bouchard.

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ABSTRACT

The Sheldon Point deposit is a linear ridge that reaches an elevation of 45 metres above sea level and is composed primarily of gravel, but also includes sand, fine grained sediments and diamict. The deposit is interpreted as a glaciomarine end moraine, formed when Late Pleistocene ice grounded on the isostatically depressed coastal lowlands of southern New Brunswick at a time of relatively high sea level. The deposit offers a "window" into glacial and glaciomarine sediments that are seldom observed above sea level.

The Sheldon Point deposit is well exposed due to gravel extraction and eroding beach bluffs. There have been several C-14 dates obtained on shell material and peat moss from the deposit. Deposition is controlled by the position of the glacial margin, sediment discharge by subaqueous meltwater channel outlets, fluctuation of the ice margin, sea level, sediment-gravity flows, and bedrock topography.

The deposit represents a time transgressive sequence from a tidewater glacier to subaerial exposure. The deposit records the nature of sedimentation from approximately 14 000 yr BP until 10 000 yr BP and is sedimentologically complex. Two re-advances occurred during this time span: One at approximately 12 800 - 12 500 yBP and the second between 11 800 and 11 200 yBP.

RÉSUMÉ

Le dépôt de Sheldon Point, crête linéaire atteignant une altitude de 45 m au-dessus du niveau de la mer, est princi-palement composé de gravier, mais il comporte également du sable, des sédiments fins et du diamicton. On considère ce dépôt comme une moraine frontale glaciomarine, qui s'est formée lorsque les glaces du Pléistocène supérieur ont pris base sur les plaines littorales en dépression isostatique du sud du Nouveau-Brunswick, à une époque où le niveau de la mer était relativement élevé. Le dépôt présente une fenêtre sur des sédiments glaciaires et glaciomarins rarement observés au-dessus du niveau de la mer.

Le dépôt de Sheldon Point est bien exposé par suite de l'extraction de gravier et de l'érosion des falaises. On a obtenu plusieurs datations au carbone 14 sur les coquillages et la tourbe en provenance du dépôt. Le dépôt est contrôlé par la position de la marge glaciaire, la sédimentation causée par les décharges de chenaux d'eau de fonte subaquatiques, la fluctuation de la marge glaciaire, le niveau de la mer, les mouvements de gravité des sédiments et la topographie du substrat rocheux.

Le dépôt représente une paragénèse transgressive à partir d'un glacier de marée jusqu'à une exposition subaérienne. Ce dépôt présente la nature de la sédimentation remontant à environ 14 000 années BP jusqu'à 10 000 années BP, et il est sédimentologiquement complexe. Deux ré-avancées glaciaires ont eu lieu au cours de cette période : l'une à environ 12 800 à 12 500 années BP, l'autre entre 11 800 et 11 200 années BP.

Acknowledgements

I would like to thank all the people who made this thesis possible and I hope that I do not miss anyone. Firstly, I would like to thank Dr. David Scott, my supervisor, for taking me on as a graduate student and allowing me the latitude to develop my own ideas while keeping me on track during the final stages of completion. I would like to thank Dr. David Piper for being the external examiner, under short notice, and for the insights that he provided. I am greatly indebted to my committee members Dr. Ron Boyd and Ralph Stea for their constant supervision throughout my stay at Dalhousie and particularily Ralph who argued, questioned and inspired the development of the thesis. I also thank Dr. Paul Schenk for his participation in the thesis defence.

I would also like to thank all the people in New Brunswick who helped make this thesis possible. Firstly, I would like to thank Alan Seaman, Dr. Arthur Ruitenberg, Sheila Watters, and Jacques Thibault of the New Brunswick government for their ideas and assistance in the field. I would also like to thank the operators and employees of the Gulf Operators and the Chittick and Ellis gravel pits who greatly assisted me in the field and allowed free access to the gravel pits. I thank

Jenny and Ron M^{ac}Williams for providing accommodation and support during my stays in Saint John. I would also like to thank the participants of the 1987 NATO field trip which stopped at my thesis area and Dr. R. Mott who visited the study area and provided the results of the pollen analysis of the peat deposit within the study area.

There were many people at Dalhousie who assisted in the final thesis preparation particularly Francine M^{c}Carthy and Veysi Baki. I am greatly indebted to Cecily Honig for reviewing and editing the final drafts of the thesis. Finally, I would like to thank Craig for his continuous support and his assistance during the final stages of preparation of the thesis.

CHAPTER 1

Introduction

The Thesis Topic

Sheldon Point is located in southern New Brunswick in the coastal lowlands along the north shore of the Bay of Fundy in the city of Saint John (Figure 1.1). The coastal lowlands of southern New Brunswick (Gadd 1973; Rampton et al. 1984) and Maine (Bloom, 1963; Stuiver and Borns 1975) were below sea level during the late Wisconsinan as a result of glacial isostatic depression and rebounded following deglaciation (Figure 1.1). Similar emerged glaciomarine deposits have been studied in Maine (Bloom, 1963; Stuiver and Borns, 1975; and Smith, 1983), Nova Scotia (Welsted, 1976; Wightman, 1980), in the area of the glacial Champlain Sea of the St. Lawrence Lowlands (Hillaire-Marcel, 1980; and Wagner, 1970), Washington (Powell, 1981; Balzarini, 1983; and Domack, 1983), British Columbia (Hickock et al., 1981), and Ireland (M^{c}Cabe et al. 1984). The exposure of this coastal compartment offers a "window" into glacial and glaciomarine sediments that are infrequently observed above sea level.

The Sheldon Point deposit is the southernmost of three glacially deposited ridges found in West Saint John. These ridges occupy the buried paleovalley of the

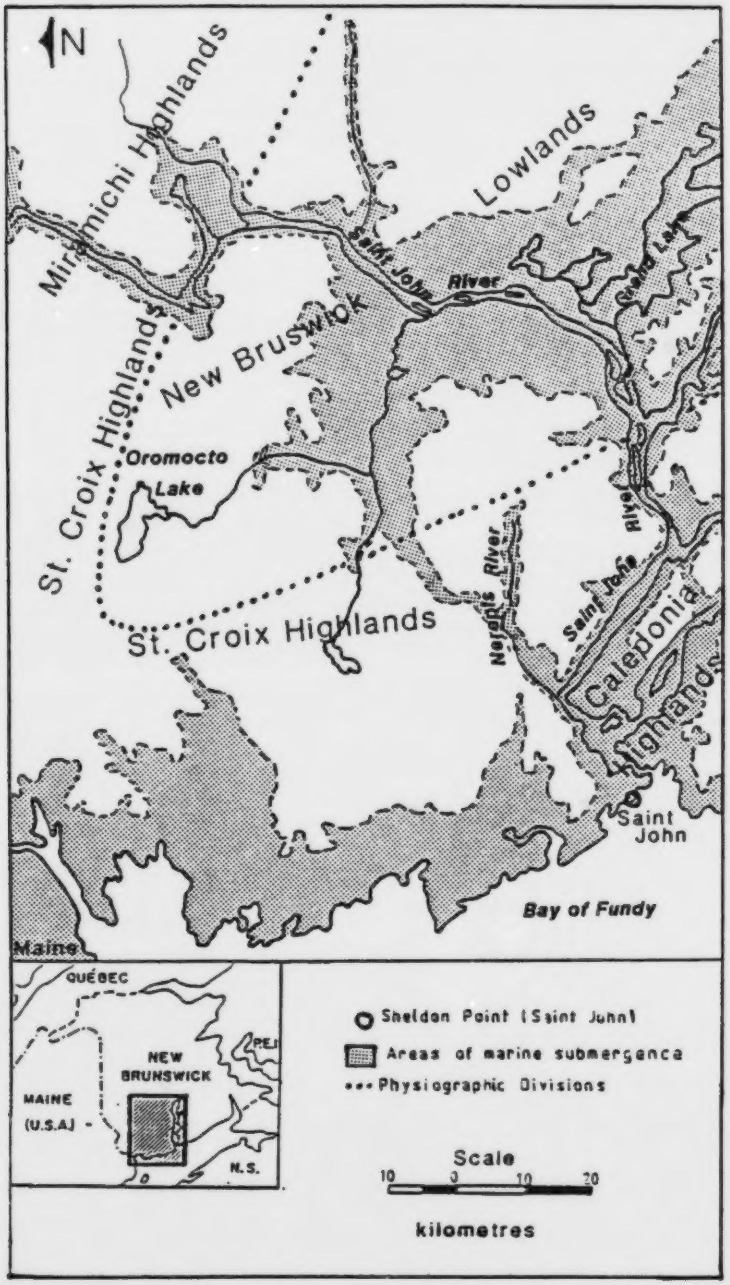

Figure 1.1. Map of southern New Brunswick illustrating the location of Sheldon Point, areas of marine submergence, and physiographic divisions (adapted from Thibault and Seaman, 1985).

Saint John River (Hawkins, 1978) and are believed to represent end moraines (Gadd, 1973; Rampton _et_ _al_., 1984). Gadd (1973) and Rampton _et_ _al_. (1984) have interpreted these end moraines as representing the position of the northward retreat of the late Wisconsinan ice from southern New Brunswick. These deposits have not, however, been studied in sufficient detail to confirm this hypothesis. The study area is approximately 2 km by 750 m with a maximum elevation of 45 m above present sea level. The deposit is composed of a complex assemblage of gravel, sand, clay, and diamict. Some of the oldest dated shell material in the Bay of Fundy-Gulf of Maine area (Rampton _et_ _al_., 1984) was obtained from the Sheldon Point deposit. Carbon-14 dated shell material, ranging from 13 900 ± 620 (GSC 3354) to 11 620 ± 250 (BGS 1223) yBP, collected from different stratigraphic horizons, indicates that the deposit is time transgressive, and may provide a sedimentary record of the late stages of deglaciation, ice margin position, and sea level variations in the Saint John harbour region.

The Sheldon Point deposit was studied to determine if the deposit represents an end moraine and what it reveals about the late glacial history of southern New Brunswick.

Physiography and General Glacial Geology

Southern New Brunswick has been divided into three physiographic regions: the New Brunswick Lowlands, the St. Croix Highlands, and the Miramichi Highlands (Gadd, 1973; Rampton et al., 1984) which are illustrated in Figure 1.1. Saint John lies in an area of low relief (stippled area Figure 1.1) adjacent to the Bay of Fundy. This area is bounded to the north by a range of hills trending northeastward, known as the St. Croix Highlands. North of these hills is another area of low relief, the Central Lowland (part of the New Brunswick Lowlands), flanked on its northwest margin by the well defined ridge of the Miramichi Highlands. Immediately to the east of Saint John lie the northeast trending Caledonia Highlands.

The New Brunswick Lowlands generally lie below 120 m elevation, and during the late Wisconsinan glaciation were extensively inundated by the sea (Figure 1.1). These lowlands are generally underlain by Pennsylvanian age sandstones, siltstones, shales, and conglomerates (Thibault and Seaman, 1985). The St. Croix Highlands are composed of steeply folded Paleozoic sedimentary and volcanic strata, intruded by granitoid rocks of Middle Devonian and Early Carboniferous age (Thibault and Seaman, 1985). The St. Croix Highlands are considered highlands because of their relative elevation above the surrounding lowlands; they reach heights of 300 m. The northern margin of the New Brunswick Lowlands are bounded by the southeastern Miramichi Highlands, formed of Silurian greywacke and slate. This sequence has been intruded by Devonian granitic plutons and folded during the Acadian orogeny (Rampton et al., 1984). Immediately to the east of Saint John, the Caledonia Highlands rise to approximately 300 m and are underlain by Precambrian and faulted Carboniferous rocks (Rampton et al., 1984). Limited geomorphologic evidence (deeply weathered bedrock, and intensely oxidized soils) suggest that the Caledonia Highlands were not glaciated during the late Wisconsinan (Rampton et al., 1984).

The Saint John River Valley originates in the Miramichi Highlands and cuts through the previously described landscape (Figure 1.1). The Saint John River cut through the St. Croix Highlands creats the greatest relief in the area. The river is an important aspect in the landscape of southern New Brunswick and probably formed during the late Cenozoic (Rampton et al., 1984). Rampton et al. (1984) indicated that the southern course of the Saint John River appears to have been diverted from an earlier, pre-Wisconsinan, northeastwardly course to the Northumberland Strait.

The distinct physiographic regions are directly affected the deglaciation pattern in southern New Brunswick. The direction of ice flow over southern New Brunswick, derived from striations and geomorphologic landforms, reflects a southward and southeastward trend (Rampton et al., 1984). Rampton et al. (1984) reported striae related to three patterns of ice flow in the Saint John area which are all interpreted as late Wisconsinan (Rampton et al., 1984). They indicate initial glacial flow from the northwest (North Maine ice divide), followed by flow from the north-northwest (Gaspereau ice centre), and finally from the north (Gaspereau ice centre). Rampton et al. (1984) identify the Gaspereau ice centre and the North Maine ice divide as the ice centres controlling sedimentation in southern New Brunswick during the late Wisconsinan (Figure 1.2). Rampton et al. (1984) placed the Gaspereau ice centre (G Figure 1.2) in the New Brunswick Lowlands north and east of Saint John. They centred the North Maine ice divide (NM Figure 1.2) in the area of the Boundary Mountains and extended the ice margin into southern New Brunswick. The North Maine ice divide effectively blocked the Laurentide ice sheet from extending into New Brunswick (Rampton et al., 1984).

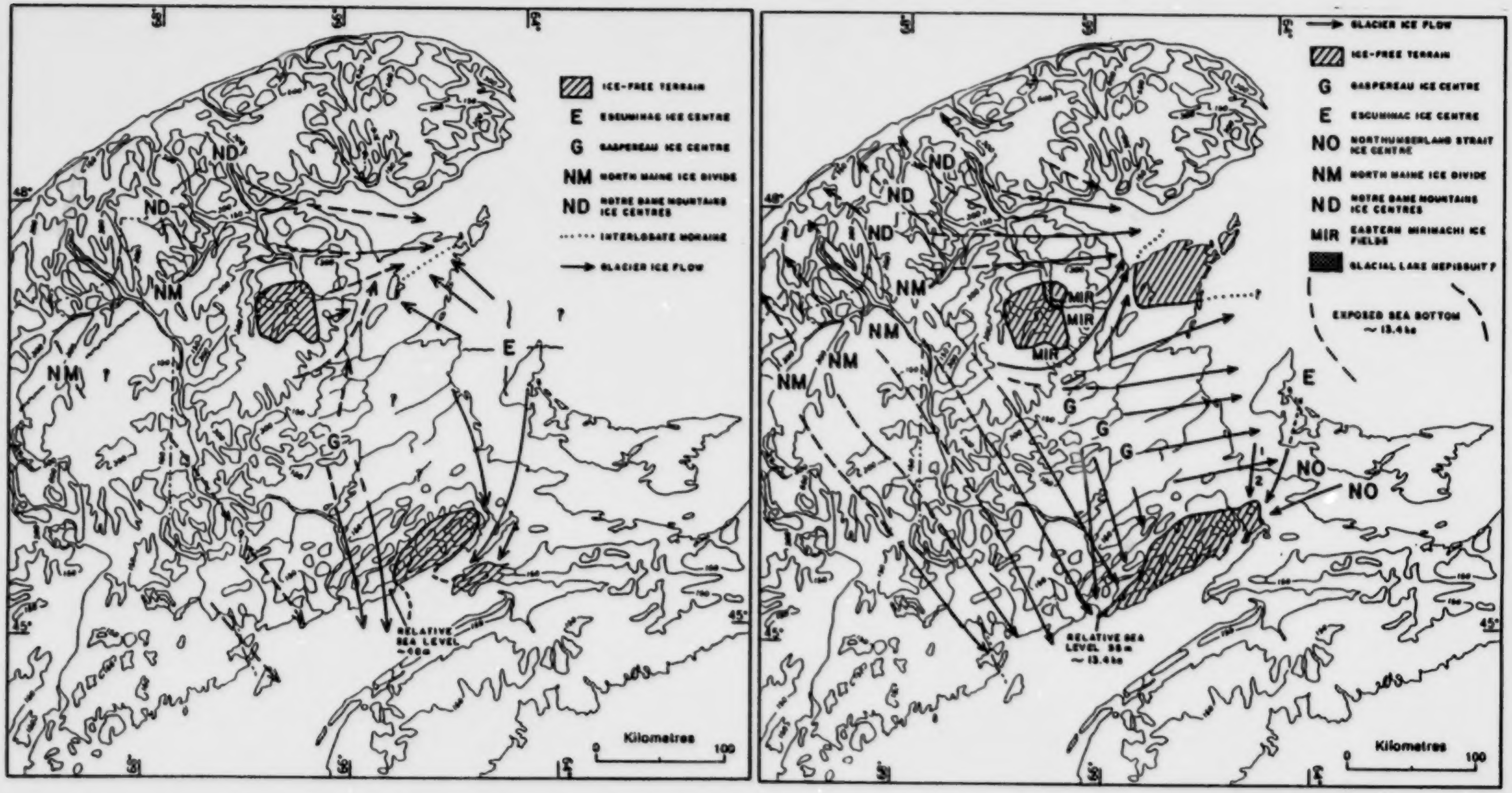

Figure 1.2. Map showing controlling ice centres from approximately (left) 14 000-13 500 yBP; (right) 13 500-12 700 yBP. (After Rampton et al., 1984)

Morphology of the Saint John Region

The Sheldon Point deposit is outlined in Figure 1.3, along with other moraine-like features in the Saint John region. The general trend of the features in this area is southwest-northeast and this reflects the local bedrock.

The bedrock in the Saint John region is complex and major lithologic boundaries are controlled by strike which is approximately northeast-southwest. The terrane around Saint John was described by Currie (1986): (p.279)

> The Avalonian terrane around Saint John exhibits basement of tonalitic gneiss veneered by a shelf type metasedimentary sequence. These units are intruded and overlain by volcanic-plutonic complexes of Late Proterozoic age emplaced in three stages. Mafic magmatism accompanied by submarine slumping heated and remobilized older rocks about 770-730 Ma. Calc-alkaline magmatism, mainly subaerial with minor submarine and volcaniclastic sedimentation passed into Cambro-Ordovician sedimentation. Silurian rocks occur only as a fault-bounded slice and Devonian rocks are absent. Coarse clastic rocks of Carboniferous and Triassic age accumulated during deformation.

Bedrock is exposed almost exclusively in the Saint John region except for four areas where Wisconsinan glacial sediments mask the underlying bedrock geology. These four areas, one in west Saint John and the remaining three in east Saint John are outlined on Figure 1.4. Two of these areas are believed to

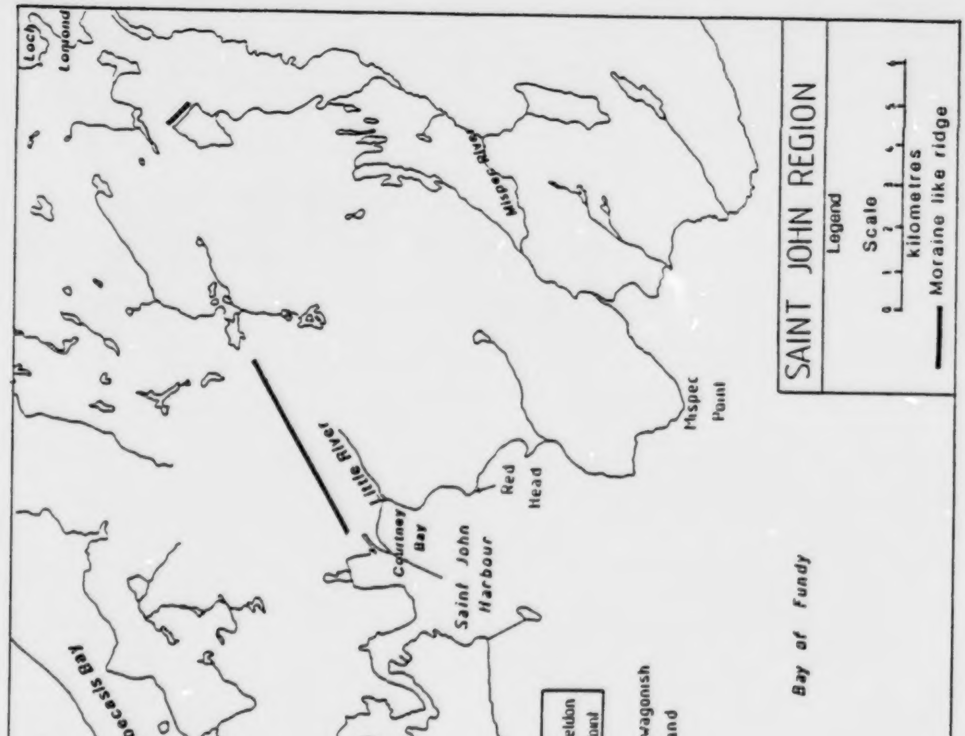

Figure 1.3. Map of the Saint John Region showing the study area.

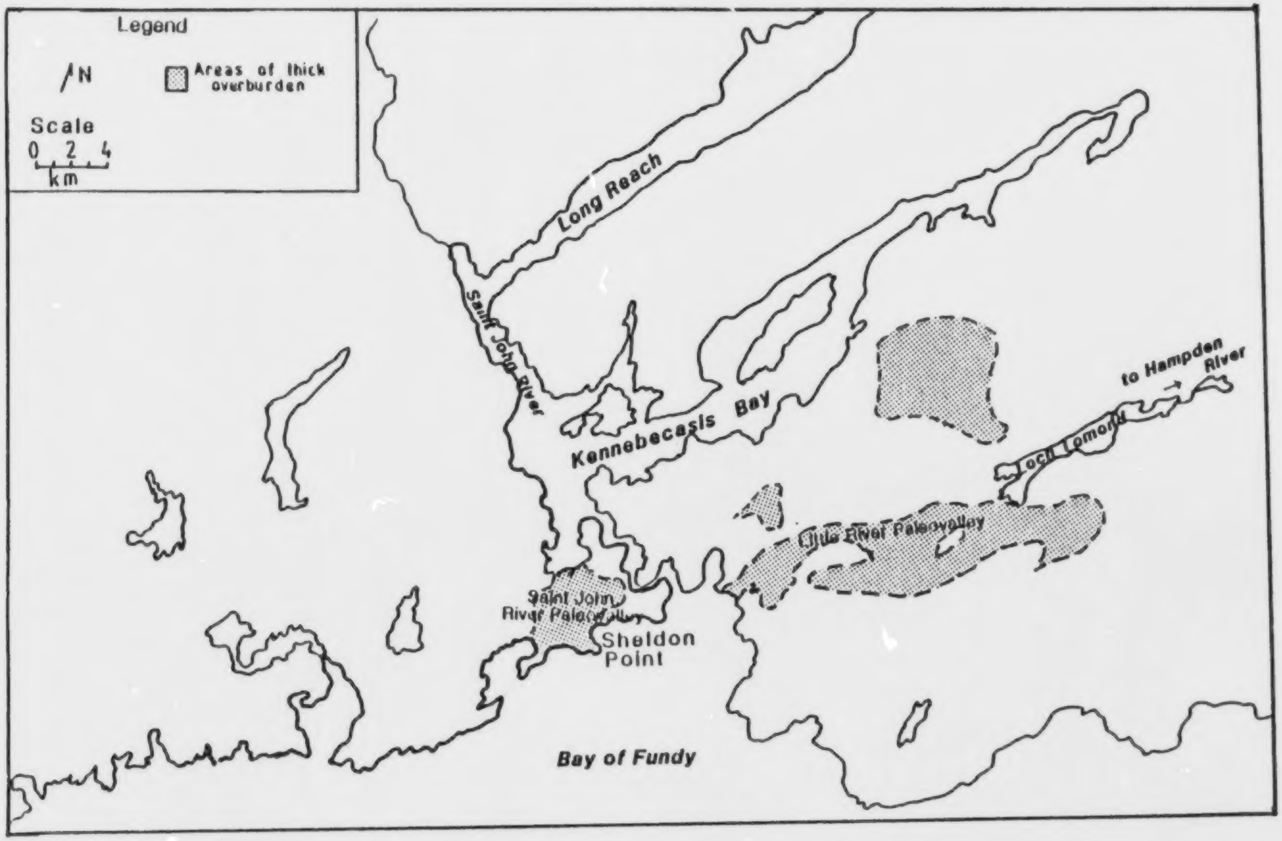

Figure 1.4. Map of the Saint John Region showing areas of thickened overburden.

represent buried bedrock valleys, the Saint John River (Hawkins, 1978) and the Little River (Melvin, 1966) paleovalleys (Figure 1.4). Seismic profiles completed across these two areas are illustrated in Figure 1.5.

In west Saint John, Hawkins (1978) completed seismic work indicating that the buried river valley reaches a depth of 90 m below sea level (b.s.l.) (Figure 1.4 and 1.5). The buried river valley connects South Bay with the Bay of Fundy and marine seismic data, collected by Emery Holzl and Associates (1968) south of the study area, support Hawkins' (1978) findings. Figure 1.4 was derived by combining data and maps from Hawkins (1978) and from Emery Holzl and Associates (1968). Several authors (Hawkins, 1978; Thibault and Seaman, 1985; Flaherty, in progress; and others) have postulated that this buried river valley represents a pre-late Wisconsinan Saint John River valley. Thibault and Seaman (1985) suggest that the present outlet formed as a result of the damming of the paleovalley outlet by late Wisconsinan glacial sediments.

In east Saint John, the Little River Valley (Figure 1.5) was filled with as much as 30 m of unconsolidated Wisconsinan sediments (Melvin, 1966). The ancient river linked Loch Lomond with Courtney Bay (Saint John Harbour). Glacial deposition at the shore of Loch Lomond diverted water down the Mispec River and Melvin (1966)

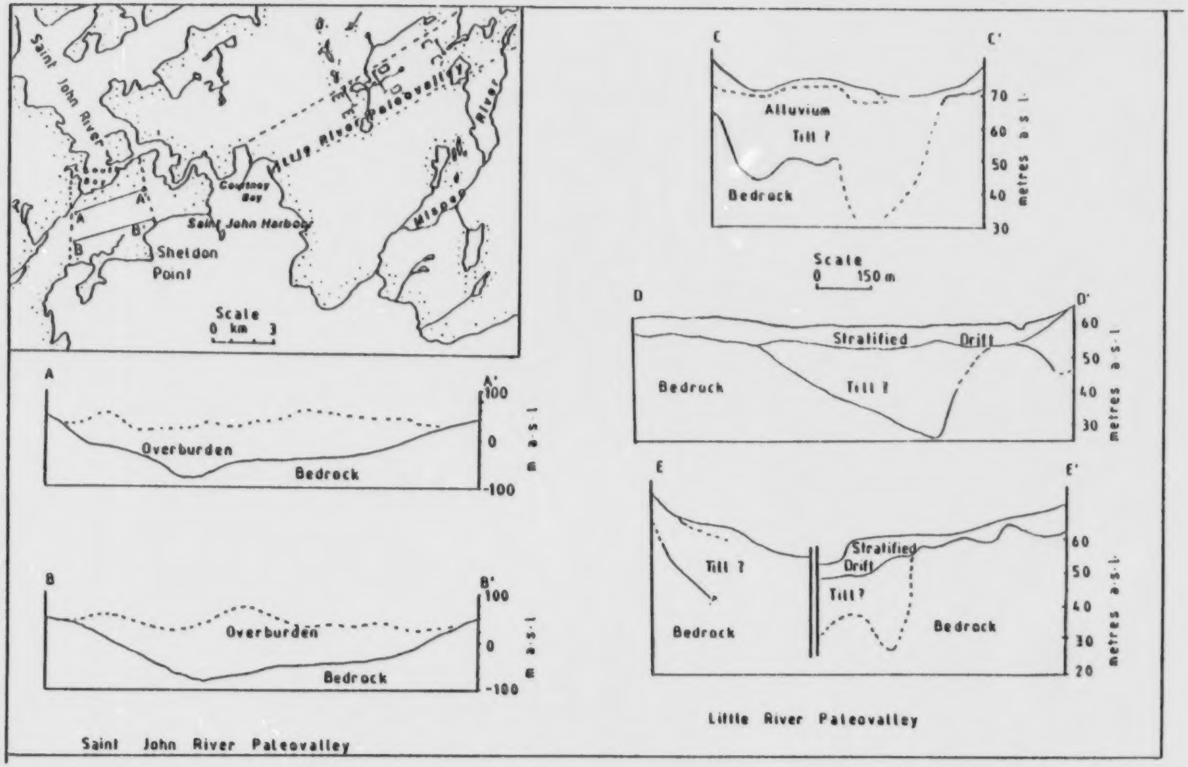

Figure 1.5. Illustration of the results of seismic profiles from the buried Little River and Saint John River paleovalleys (after Melvin, 1966; and Hawkins, 1977).

speculated that the Little River was a pre-late Wisconsinan buried outlet of the Hampden River east of the Saint John region. This buried river valley is oriented along bedrock strike.

Three ridges occupy the area of the buried Saint John River paleovalley (Figure 1.6): 1) the most southerly is the Sheldon Point deposit 2) approximately 2 km north is the Manawogonish moraine and 3) north of the Manawogonish moraine is the South Bay moraine.

The study area has been well exposed by extensive gravel quarrying. Extraction in the present gravel pits began in the early 1950's; the active pits the Gulf Operator's pit (GO pit) and the Chittick and Ellis pit (C&E pit), have been outlined in Figure 1.7. The C&E pit contains three lifts[1]: 1) The lowest lift has 15 - 30 m faces and is approximately 15 m above sea level (a.s.l.) 2) The middle lift has a 10 - 15 m face and is approximately 25 m a.s.l. and 3) the upper lift has a 5 m face and is 35 - 40 m a.s.l. The GO pit also contains three lifts. The lowest lift is approximately 25 m a.s.l., the middle lift is approximately 30 m a.s.l., and the upper lift is approximately 35 m a.s.l.

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[1] The term "lift" is used by Hunter and Associates (1982) to describe areas or levels of gravel extraction within a gravel pit.

Figure 1.6. Map of west Saint John showing local morphology. (See inset in back pocket.)

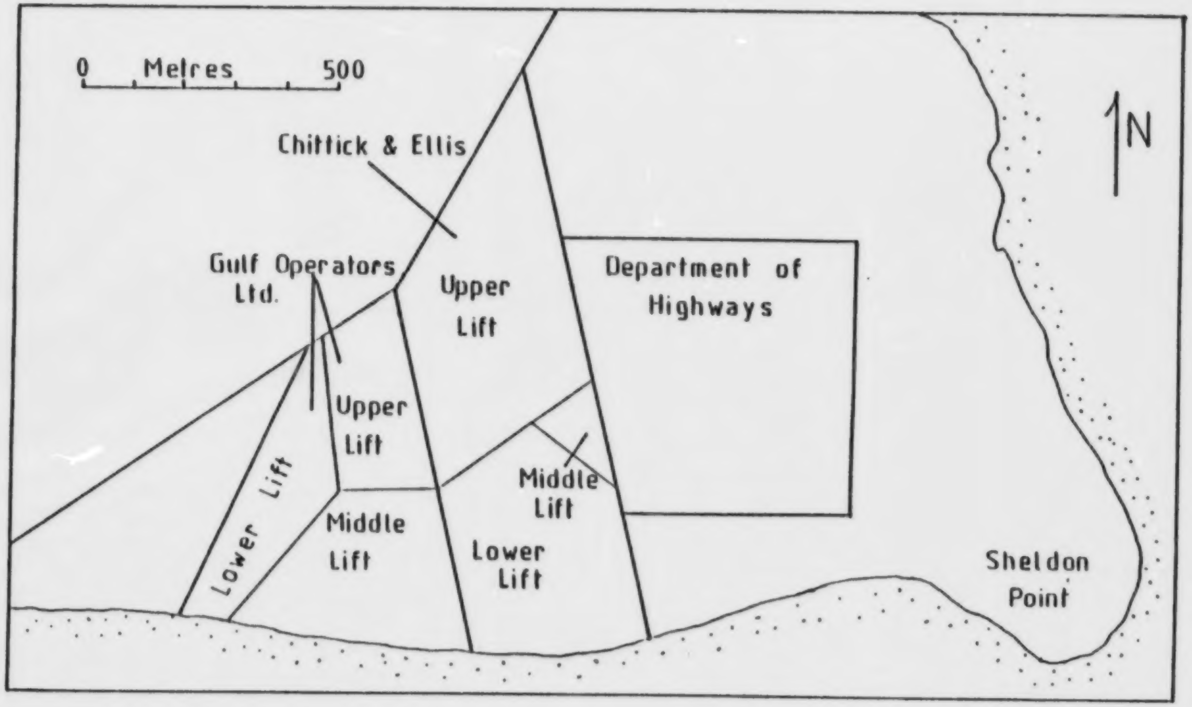


Figure 1.7. Diagram illustrating the location of the gravel pits and their respective lifts at Sheldon Point.

All three lifts have 5 m faces. Hunter and Associates (1982) reported from both pits (p.212):

> A pebble count of the gravel gave the following assemblage in decreasing order of abundance: quartzite, basic igneous rocks, basic volcanic rocks, granite, acid volcanic rocks, quartz, sandstone, and hornfels.

These lithologies can be found in the immediate Saint John area.

The northeast/southwest trend of the ridge is accentuated by the areas of most extensive gravel extraction in the 1984 colour aerial photograph (Figure 1.8) and the colour stereographic sequence (Figure 1.9). Faint linear ridges can be observed in the bush and a bedrock ledge can be observed at the southern end of Sheldon Point. A lobe-shaped deposit, accentuated by the green vegetation against the brown marsh lowland, is clearly visible on the north side of the deposit.

The 1935 black and white aerial photograph (Figure 1.10), illustrates the sharp definition of the ridge of the Sheldon Point deposit prior to extraction, the linear beach-like ridges superimposed on the Sheldon Point deposit, and the lobe shaped deposit on the north slope. The Manawogonish moraine, the next ridge to the north, is evident. Small, lobe-shaped deposits, similar to the one on the north slope of the Sheldon Point deposit, are clearly visible on the southern flank of

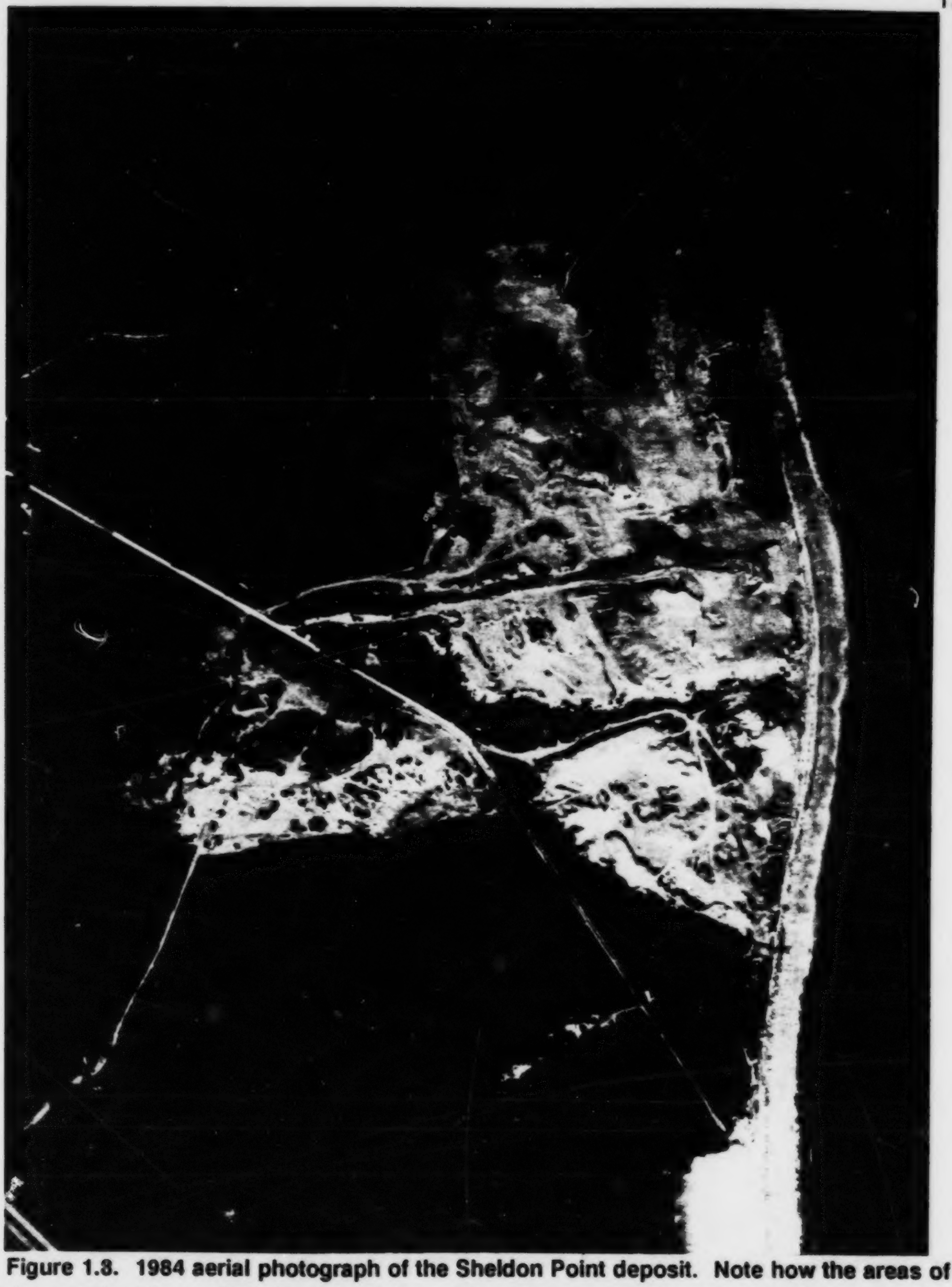


Figure 1.3. 1984 aerial photograph of the Sheldon Point deposit. Note how the areas of primary extraction outline the orientation of the ridge passing through the Sheldon Point deposit (North is towards the left side of the page).

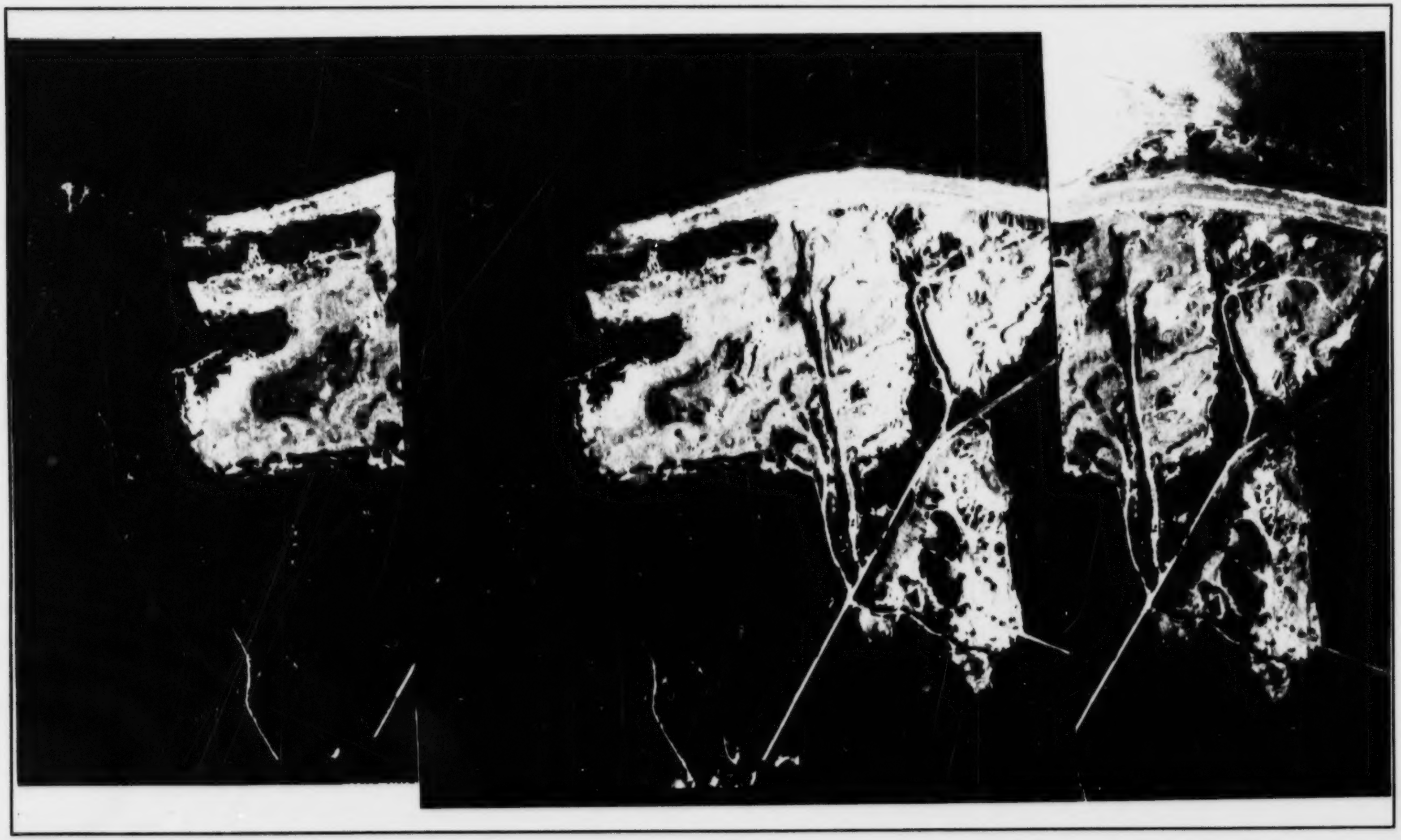


Figure 1.9. Stereographic pairs of 1984 aerial photographs. Note the areas of primary extraction outline the trend of the deposit.

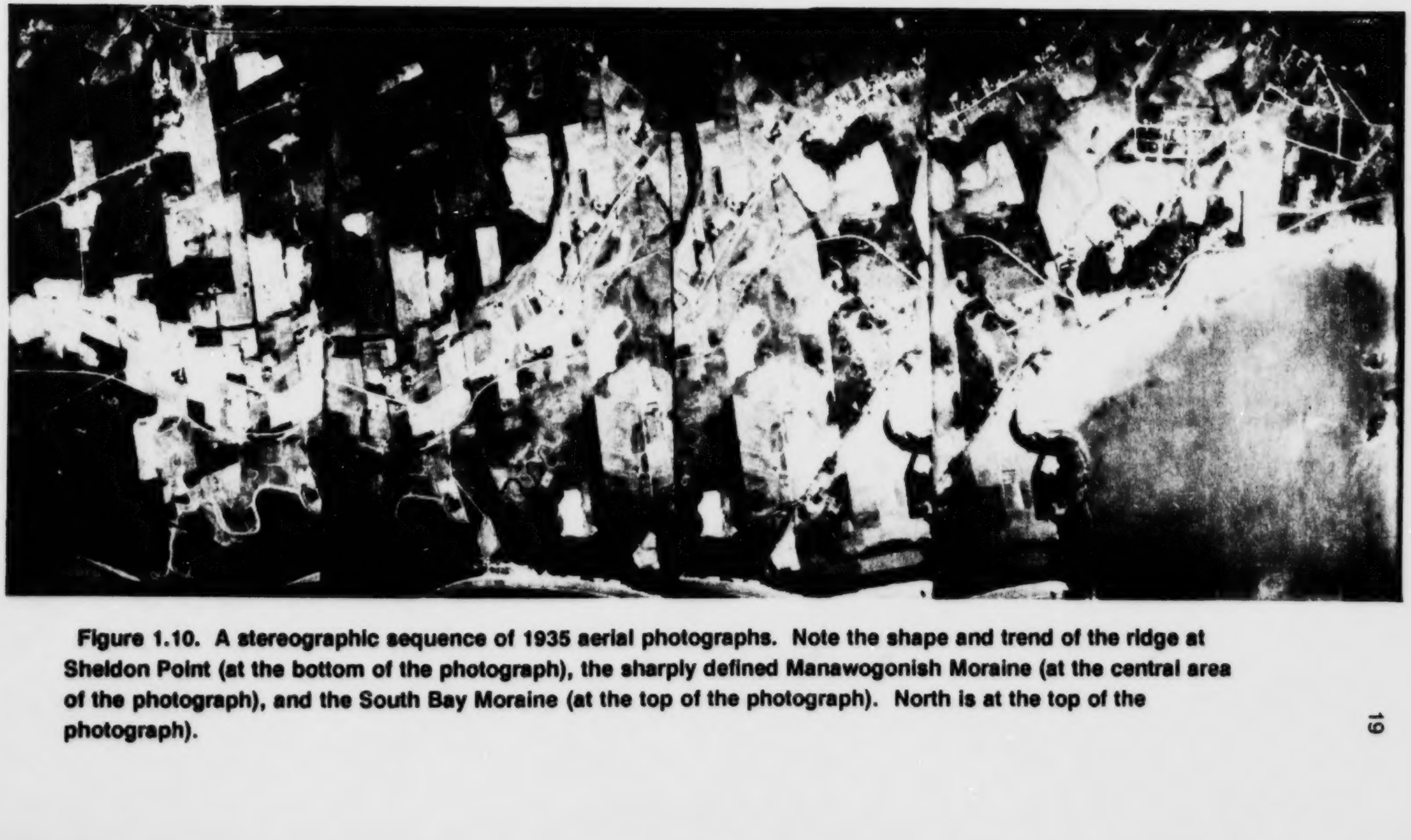


Figure 1.10. A stereographic sequence of 1935 aerial photographs. Note the shape and trend of the ridge at Sheldon Point (at the bottom of the photograph), the sharply defined Manawogonish Moraine (at the central area of the photograph), and the South Bay Moraine (at the top of the photograph). North is at the top of the photograph).

the Manawogonish moraine. The arcuate shape of the moraine is outlined by the roads. Linear ridges can be seen in some areas on the south face, and the northern slope is clearly defined and steep. There are no lobe-shaped deposits on this northern slope. To the north of the Manawogonish moraine is a low, flat-lying area. This flat-lying area is bounded on the north by the South Bay moraine, visible at the top of the photograph. The north slope of this moraine is slightly steeper than the south slope and there are no lobe-shaped deposits on either side.

The sediments within the buried river paleovalleys and the Saint John harbour area were effected by elevated sea level. Table 1.1 summarizes reported measurements of marine limits in the Saint John Harbour area. In addition, certain observations of the morphology of the area indicate sea level variations. For example, the ridges superimposed on the south side of the Manawogonish moraine and the absence of ridges on the South Bay moraine suggest that sea level fell below the height of the Manawogonish moraine (65-70 m) while the ice was grounded at that location and suggest, furthermore, that the South Bay moraine was not exposed to the sea. The planed off upper surface and the lobe-shaped deposits on the north slope of the Sheldon Point deposit suggest that it was subjected to marine

Table 1.1
Reported altitudes of the marine limit in coastal portions of Southern New Brunswick

Location	metres (a.s.l.)	Feature	Reference
St. Croix River	70	not specified	Chalmers (1905)
Digdequash River	70	not specified	Chalmers (1905)
West of Pennfield Station	75	not specified	Chalmers (1905)
Pennfield Station	70	not specified	Chalmers (1905)
Pennfield	70	not specified	Goldthwait (1911)
Pennfield	70	marine (?) delta	Lougee (1954)
Near Spruce Lake	55	not specified	Chalmers (1905)
Saint John (Manawogonish Moraine)	50	gravel beaches along morainal ridge	Lougee (1954)
Saint John (Martello Tower)	60	strand line	Goldthwait (1914)
Saint John (not specified)	70	not specified	Goldthwait (1911)
Saint John Harbour (east side of harbour) but unspecified)	70	shoreline, location not specified	Chalmers (1894)
Hillsborough (not specified)	70	not specified	Chalmers (1905)
Petticodiac (not specified)	50	not specified	Chalmers (1905)
Saint John (east)	65-70	Little River delta	Melvin (1966)
Saint John (east)	25-30	bench on Little River delta	Melvin (1966)
Cruikshank Lake	65	marine (?) delta	Melvin (1966)
Lakewood	53	grade level of deposit	Melvin (1966)

processes after its deposition. The ice had retreated from Sheldon Point before sea level fell below the height of the deposit (45 m).

Previous Work

The study of glacial geology in New Brunswick began in the late 1800's with the Sheldon Point deposit being one of the earliest areas of study. Mathews (1879) and Chalmers (1890) were the first to describe the ridges in west Saint John and to interpret them as kames, partly or wholly of marine origin. Both authors described, in considerable detail, the sediments and glacial striations at Sheldon Point. Chalmers (1893) noted that marine clays had been overlain by till at Lancaster (now West Saint John). However, Mathews (1879) provided the most detailed morphological description of the ridges in West Saint John (previously Lancaster, Fairville, Carleton, and South Bay). He noted that the surfaces of the Sheldon Point deposit and Manawogonish moraine had been reworked by marine processes. In addition, Mathews (1879) observed that the Manawogonish moraine was much higher and had therefore protected the South Bay moraine, which lies to the north, from reworking by the sea. Mathews (1879) provided a detailed description of shell assemblages from the beach bluffs adjacent to

Sheldon Point. By the end of the 19th century, geologists had concluded that the Sheldon Point deposit had been exposed to both glacial and marine processes. It was uncertain, however, whether the glacier and the sea had been contemporaneous.

Lee (in Walton, Trautman and Friend, 1961) was the first to suggest that the sea and ice were contemporaneous in a glaciomarine association at Sheldon Point. Gadd (1973), however, completed a more detailed study of the Quaternary geology of Southwest New Brunswick and concluded that the sea and ice were not contemporaneous at Sheldon Point (Gadd, 1982).

Gadd (1973) correlated the series of ridges along the shoreline from Saint John to the Maine-New Brunswick border. Based on shell material included in the deposit, he interpreted the Sheldon Point deposit as the oldest late-glacial deposit exposed in Southern New Brunswick. In the same report, he interpreted the deposit as a bar or spit developed on a submerged moraine and used the term "wave modified moraine" on the accompanying map. Later, Gadd (1982) referred to the deposit as the Sheldon Point Moraine and concluded that moraine formation must be older than marine submergence, based on a total organic carbon date from Little Lake, north of the moraine. Furthermore, he suggested that the time period between moraine formation and marine inundation was between 1000 and 3000 years.

Wightman (1980) supported the idea that moraine formation and marine reworking were not contemporaneous. Wightman (1980, p.352) interpreted part of the Sheldon Point deposit as a Gilbert-type delta, based on the descriptions by Lee (in Walton et al., 1961, p. 50) and Gadd (1973), and photographs of the deposit included in Gadd (1973, p. 15). Rampton et al. (1984) compiled a publication and map on the Quaternary geology of New Brunswick. However, much of the information on southern New Brunswick and the Saint John area is based on the map completed by Gadd (1973) and very little new work on the Sheldon Point deposit was completed for the publication.

Thibault and Seaman (1985) proposed that the moraine complex in west Saint John formed when ice was calving into a rising sea at 13.4 to 13.0 ka yBP. The authors provided a general description of the Sheldon Point deposit but no detailed interpretation was presented.

Gadd (personal communication, 1988) most recently interpreted the sequence of events at Sheldon Point as:

> "glaciomarine deposition at the ice margin during eustatic rise of sea level; according to radiocarbon dates in the area this may have occurred as early as ca. 13 000 B.P.; later planation of the surface to produce the level surface of Figure 14 (Gadd, 1973), probably was

> marine and a later event. Although fossils and dates at this level were not available to me, I assume that it may have occurred somewhere around 12 000 B.P. or earlier."

Gadd's (1973) work remains the most detailed account of the Sheldon Point deposit prior to this thesis.

Methodology

The approach taken in this study was to map all exposures. To do this, the exposures were scaled, wherever possible, and a detailed log was compiled from the top to the bottom of the section, noting sediment type, unconformities, bedforms, and height above mean sea level (m.s.l.) of these observations. The height of the section and of the facies changes were documented using the City of Saint John maps (Sheet nos. 06N-64SE, 06N-74SW, 06N-63NE, and 06N-73NW) at a scale of 1:1200 (contour interval 2.5 ′), verified with an altimeter. The nature of the boundaries (gradational or sharp), visual grain size, colour, imbrication, and sedimentary structures were documented. In addition, the maximum dips and orientation of the dips were measured. Continuous mapping of the major facies was facilitated by using photographic mosaics of the exposure. Grain size analyses were not undertaken because of the variability in grain size within the units and throughout the deposit, and the dominance of gravel and boulder sized material. Detailed fabric and pebble lithology analysis was not undertaken.

Elevations of features were taken using an altimeter, incremented in one metre intervals. Base readings were taken at the higher high water mark on the beaches and corrected to mean water depth. The bluff or exposure was then scaled and the necessary measurements were taken. After each measurement, the altimeter was recalibrated to the initial base reading at the higher high water mark and the correction was estimated. In addition, a temporary base station calibrated to the closest bench mark was established at the weigh station in the Gulf Operators pit.

The accuracy of the readings was largely a function of weather conditions. The literature included with the altimeter suggests an accuracy within 1 m. Generally, the measurements were only accurate to within 2 to 3 metres. If more accuracy was required, three or four traverses were conducted.

The stratigraphy observed in the beach bluffs and the quarried exposures of the gravel pits was carefully logged. Facies that could be traced laterally were mapped and facies associations were also recorded. Dips and orientations of the facies were noted, using a Silva compass, so that units could be correlated between exposures. The locations of all exposures and the logs were mapped using a combination of aerial photographs, city topographic maps of the area at a scale of 1:1200, triangulation, and compass and pace traverses.

Samples of the fine-grained facies were taken to determine the benthonic foraminiferal assemblages associated with certain key facies. Where possible, shell samples were collected; the position was measured, the species identified, and material sent for carbon-14 dating. Mott (personal communication) has carbon-14 dated and completed a detailed pollen analysis of the peat deposit located in the southwestern portion of the study area.

Nomenclature

The lithofacies classification scheme adopted in this thesis is that of McCabe *et al*. (1984), Eyles *et al*. (1983) and Miall (1978). This scheme is widely accepted and can easily be applied to the Sheldon Point deposit. The four basic lithologic associations, outlined in Table 1.2, are mud, sand, gravel and diamict. These four associations have been further subdivided based on sedimentary characteristics.

This classification system was useful for the initial mapping and the detailed description of the deposit. As the mapping progressed, some of the facies could be grouped together based on unconformities and stratigraphic and sedimentologic characteristics. For interpretive purposes, the facies were grouped into nine stratigraphic units and are discussed in Chapter 2.

Table 1.2

Summary of glaciomarine lithofacies types

Diamict (D): Poorly sorted, mud-sand-gravel admixture

Dmm	Matrix-supported, massive structureless
Dmm(s)	As Dmm, with shear or fold structures
Dms	Stratified, occasionally graded, matrix-to-clast-supported, evidence of winnowing

Gravel (BG = boulder/cobble grade or PG = pebble grade):

BGmm	Matrix-supported, massive, unstratified, matrix from granules to pebbles
BGmg	Matrix-supported, stratified. Grading: normal (n), inverse (i), normal to inverse (n-i), inverse to normal (i-n)
BGcm	As BGmg, but clast-to-matrix supported
BGcmg	Clast-to-matrix supported gravel; graded
BGcg	As BGmg, but clast-supported
BGgt	Matrix-clast supported sometimes graded. Trough cross-bedded
BGgp	Matrix-clast supported sometimes graded. Planar cross-bedded
BGcmp	Planar cross-bedded clast-to-matrix supported gravel

Sand (S): Fine to coarse grade

Sm	Massive, unstratified
Sh	Parallel laminations or partings
Sr	Rippled
Sg	Graded
St	Cross-stratified
Ssd	Soft-sediment deformation

Mud (F): Fine-grained units, mainly silt and clay

Fm	Massive mud, unstratified
Fl	Clay, silt, and sand laminae, alternating beds
Fd	Laminated pebbly mudstone or laminated mud with clasts

CHAPTER 2

SEDIMENTOLOGY

The study area is a complex assemblage of gravel, sand, clay, and diamict. Facies have been grouped into nine units, based on stratigraphy and sedimentology. The unit classification scheme represents a grouping of facies that appear to have the same depositional environment. Figure 2.1 indicates the location of the cross-section (Line A-A′) illustrated in Figure 2.2. Figure 2.2, a schematic cross-section of the study area, illustrates the relationship of the individual units. The diagram provides a general understanding of the interaction of individual facies and units. Table 2.1 provides a short summary of the facies and units described in Chapter 2. Figure 2.3 is a map illustrating the location of the photographs, photologs, and profiles discussed throughout the text. Figures 2.4, 2.5, and 2.6 are mapped exposures of the study area.

UNIT 1:

Unit 1 is the stratigraphically lowest unit observed in the study area, and is exposed from the base of the pit at sea level to a maximum of 45 m. This unit

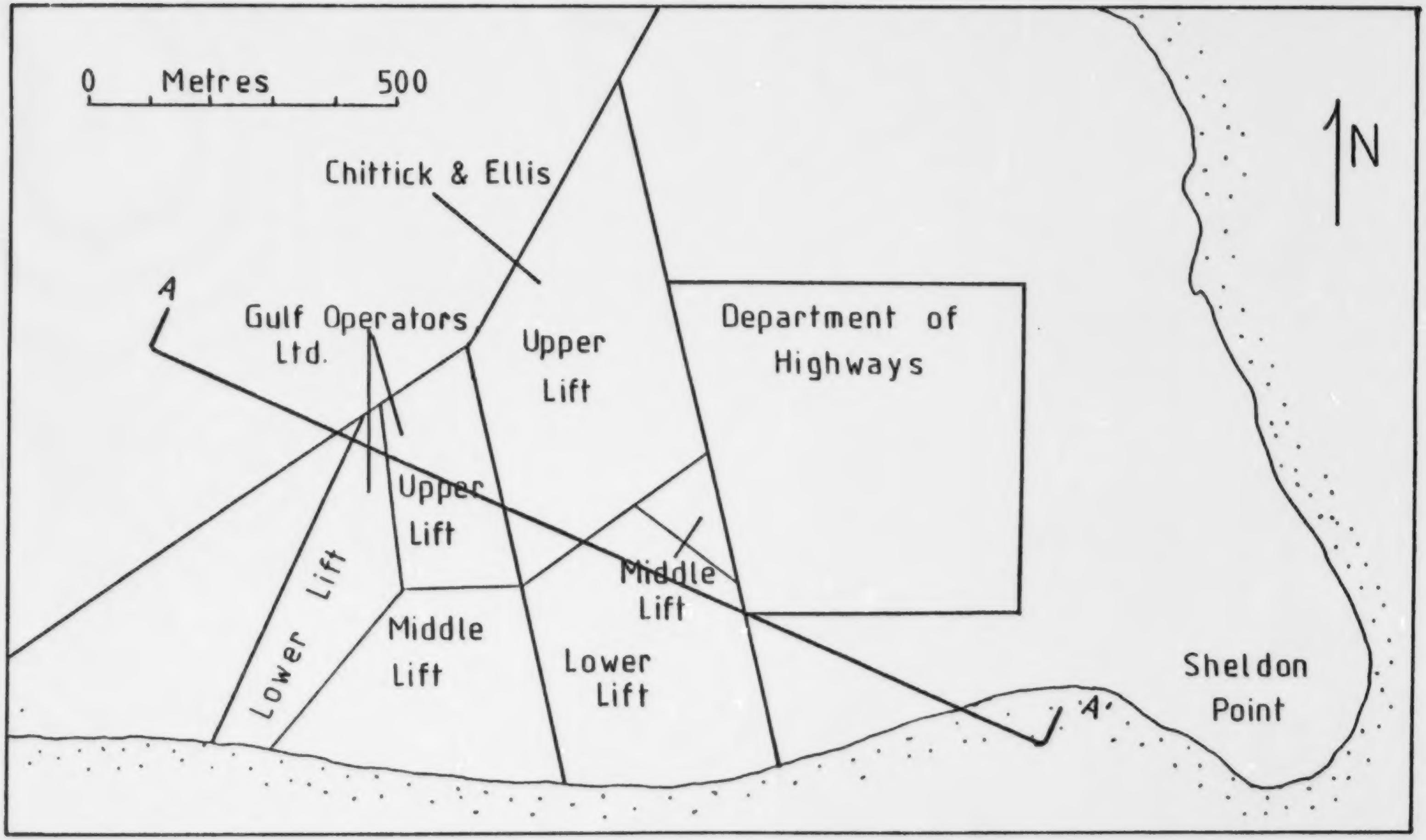


Figure 2.1. A-A' indicates the location of the cross-section (Line A-A') illustrated in Figure 2.2.

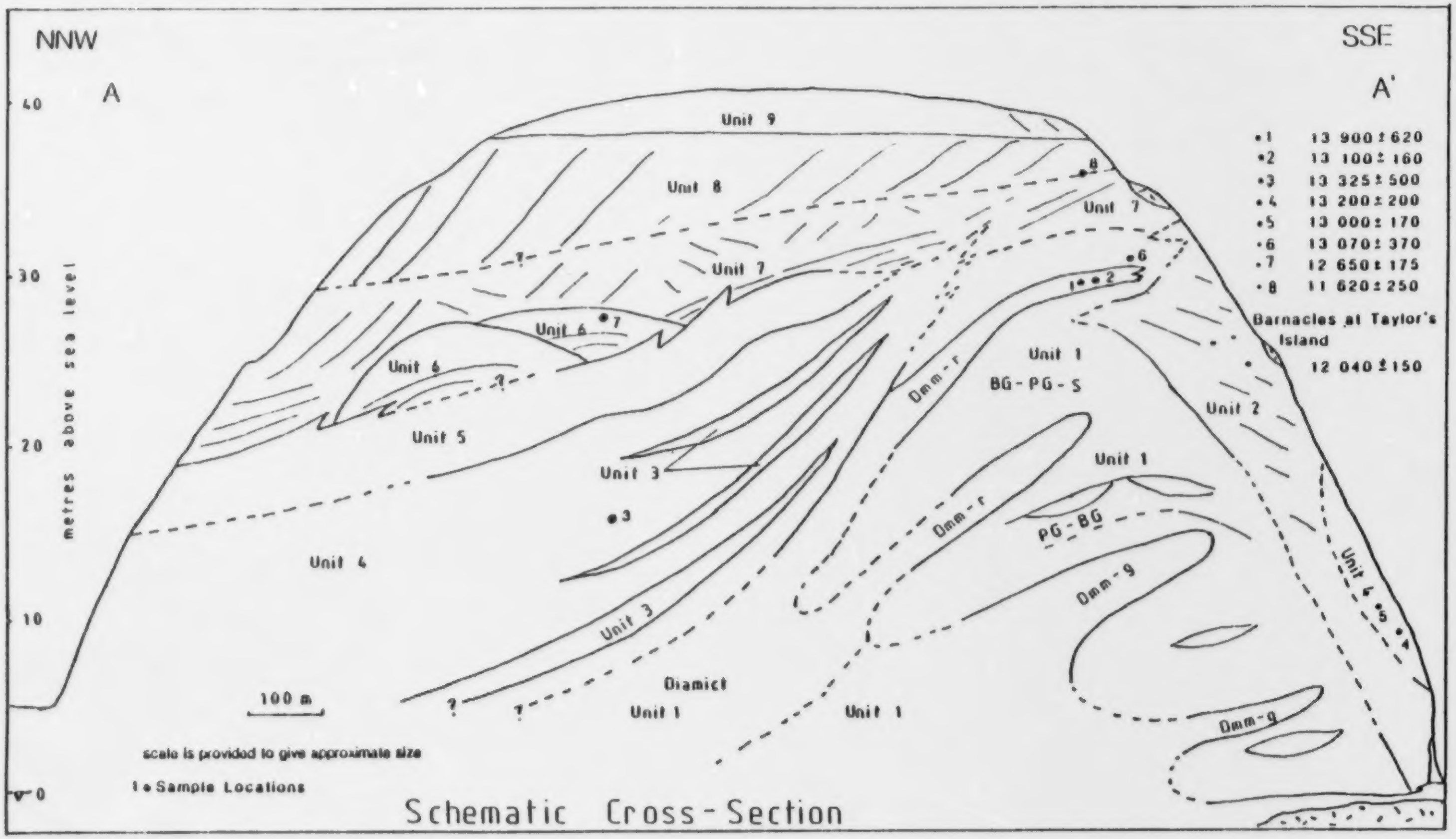


Figure 2.2. Schematic cross-section of the Sheldon Point deposit. This represents Line A-A' shown in Fig. 2.1.

Table 2.1
Summary of Units and Facies

Unit	Facies	Facies Relationship
1	grey diamict (Dmm-g) red diamict (Dmm-r) normally graded gravel (PGcmg) trough x-bedded sand and gravel (Pt-St) massive sandy gravel (PGmm) foreset gravel (BGcmp-PGcmp) grey stratified diamict (Dms-g) red stratified diamict (Dms-r) normally graded sand (Sg) x-bedded sand (St)	-diamict facies interfinger with sand and gravel facies of Unit 1 -characterized by normal faults, thrust faults were observed at one location -Unit 1 is unconformably overlain by Unit 2
2	normally graded sand (Sg) stratified sand (Sh)	-Unit 2 does not interfinger with any other deposit -Unit 2 fines upwards into unit 4 -Unit 2 was only observed on the south side of the ridge passing through the deposit, all beds were dipping southward
3	matrix supported gravel (PGmg-BGmg)	-Unit 3 is characterized by broad gravel filled troughs -Unit 3 is only observed dipping north on the north side of the ridge passing through Sheldon Point -Unit 3 interfingers with Unit 4 and unconformably overlies Unit 1
4	laminated clay, sand, and muddy gravel (Fl-Fd)	-Unit 4 is a rhythmic unit composed of fine grained materials -Interfingers and overlies Unit 3; overlies Unit 2
5	massive clay (Fm)	-Unit 5 is unconformably overlain by Unit 6 and 7 -small scale thrust faulting was observed at one location
6	stratified gravel (PGms)	-Unit 6 is unconformably overlain by Unit 7 -large normal faults were observed
7	x-stratified gravel (PGp)	-Unit 7 has widely varying flow directions
8	foreset gravel (PGp)	-Unit 8 has a northward flow direction and forms a lobe-shaped deposit
9	stratified sand and gravel beds (Ss-PGct)	-Unit 9 was observed in small ridges superimposed on several units

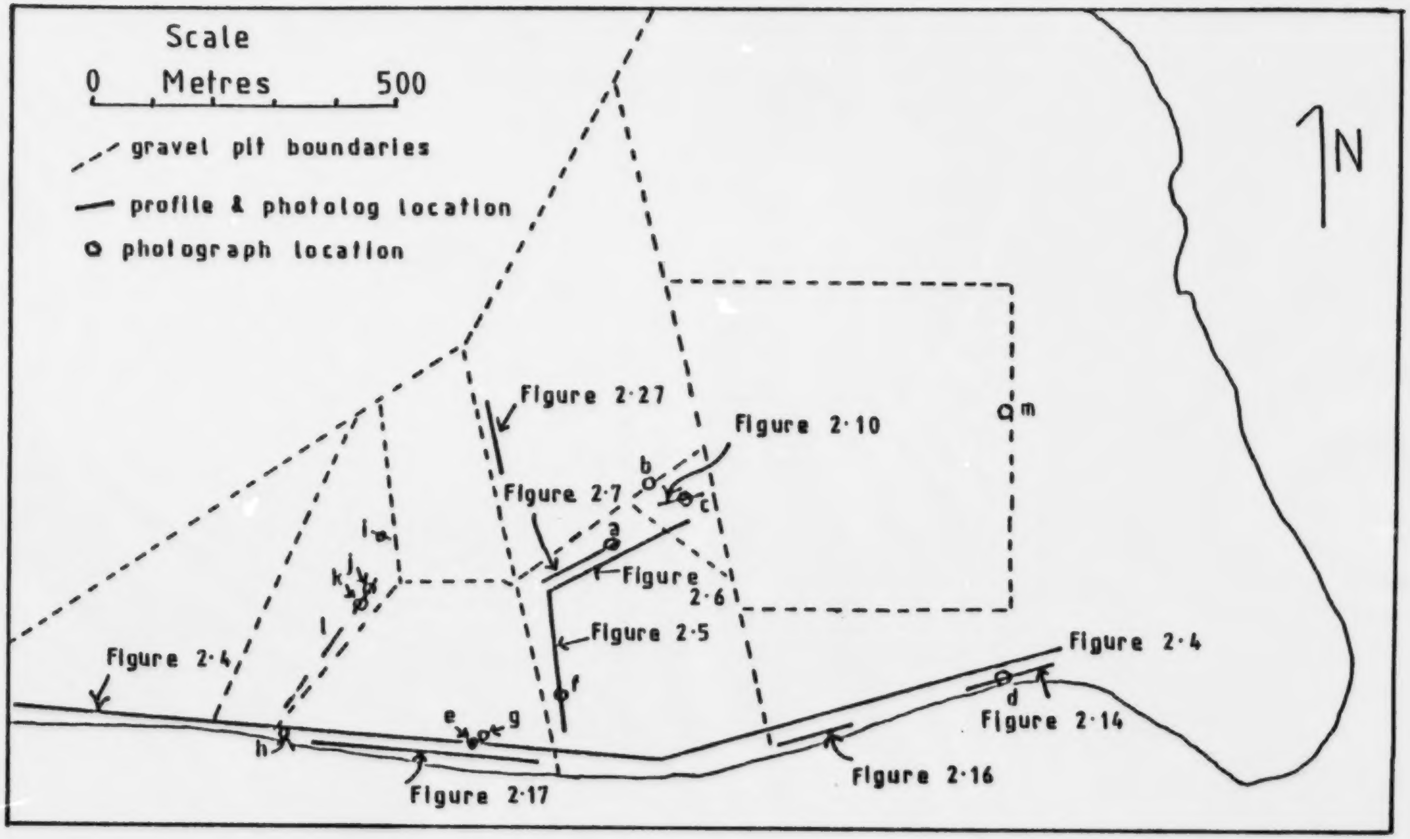


Figure 2.3. Map illustrating the location of the photographs discussed in the text.

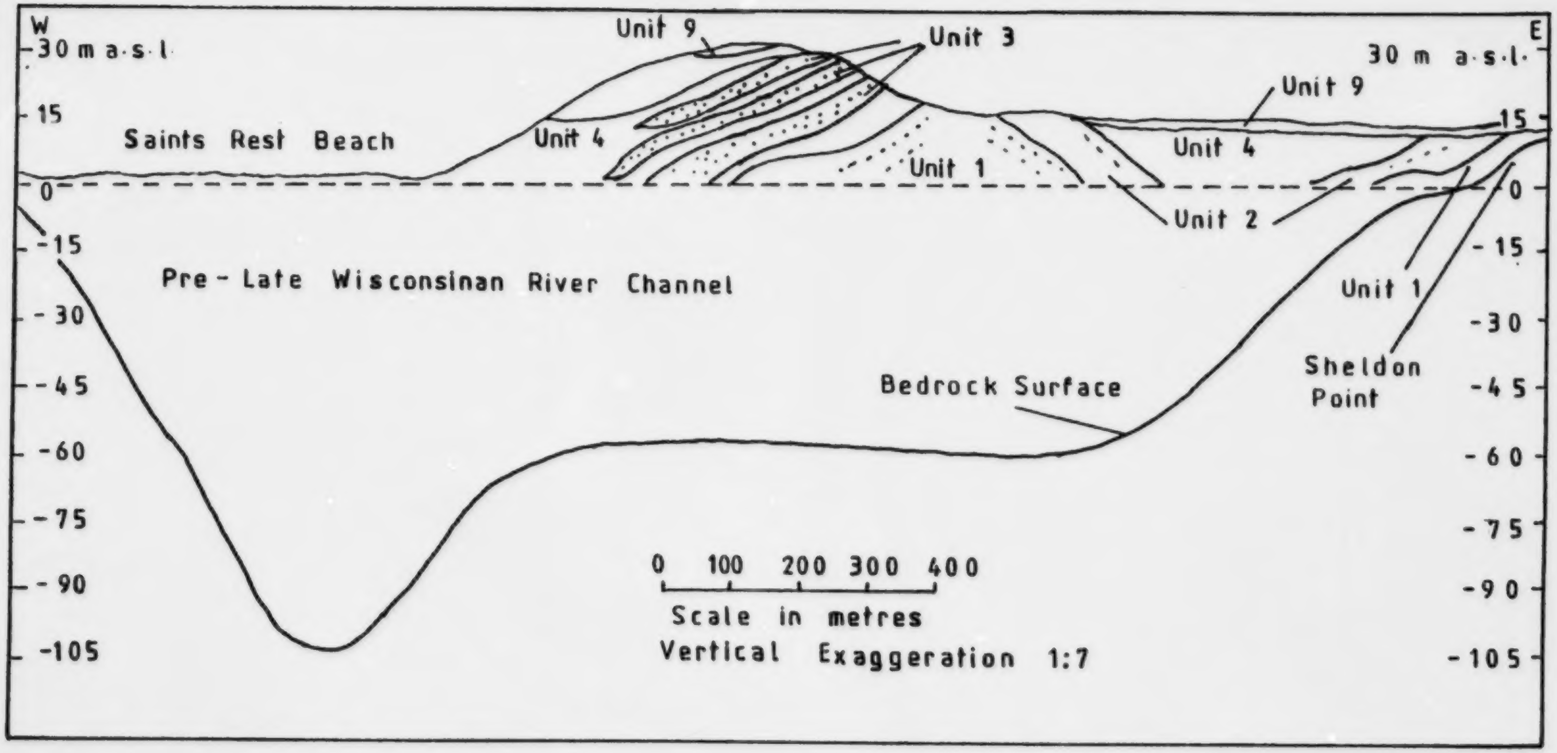


Figure 2.4. Profile between Saints Rest Beach and Sheldon Point. Illustrates the depth of the pre-late Wisconsinan River Channel and the facies association.

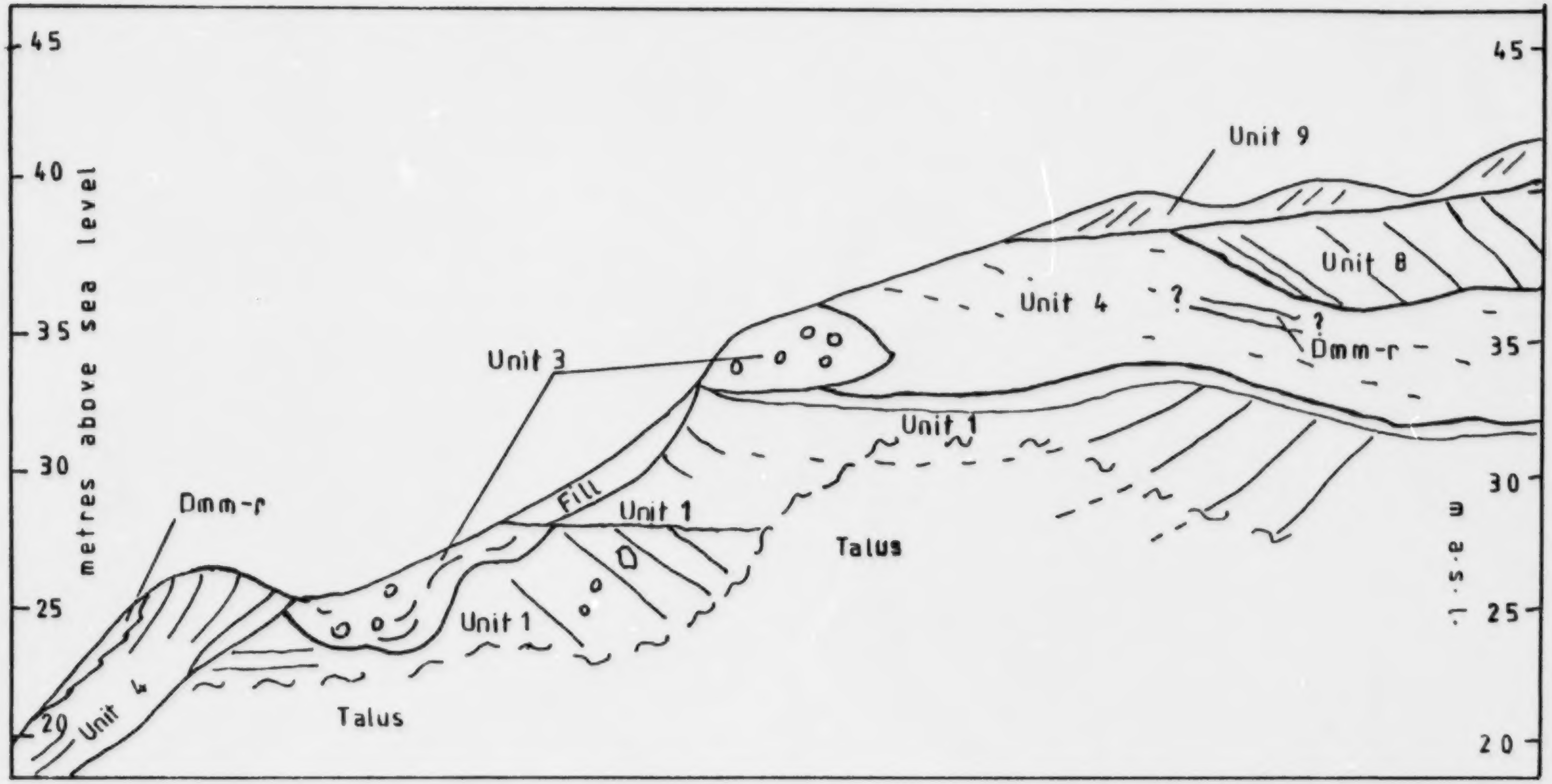


Figure 2.5. Profile of the west wall of the lower lift of the C&E gravel pit.

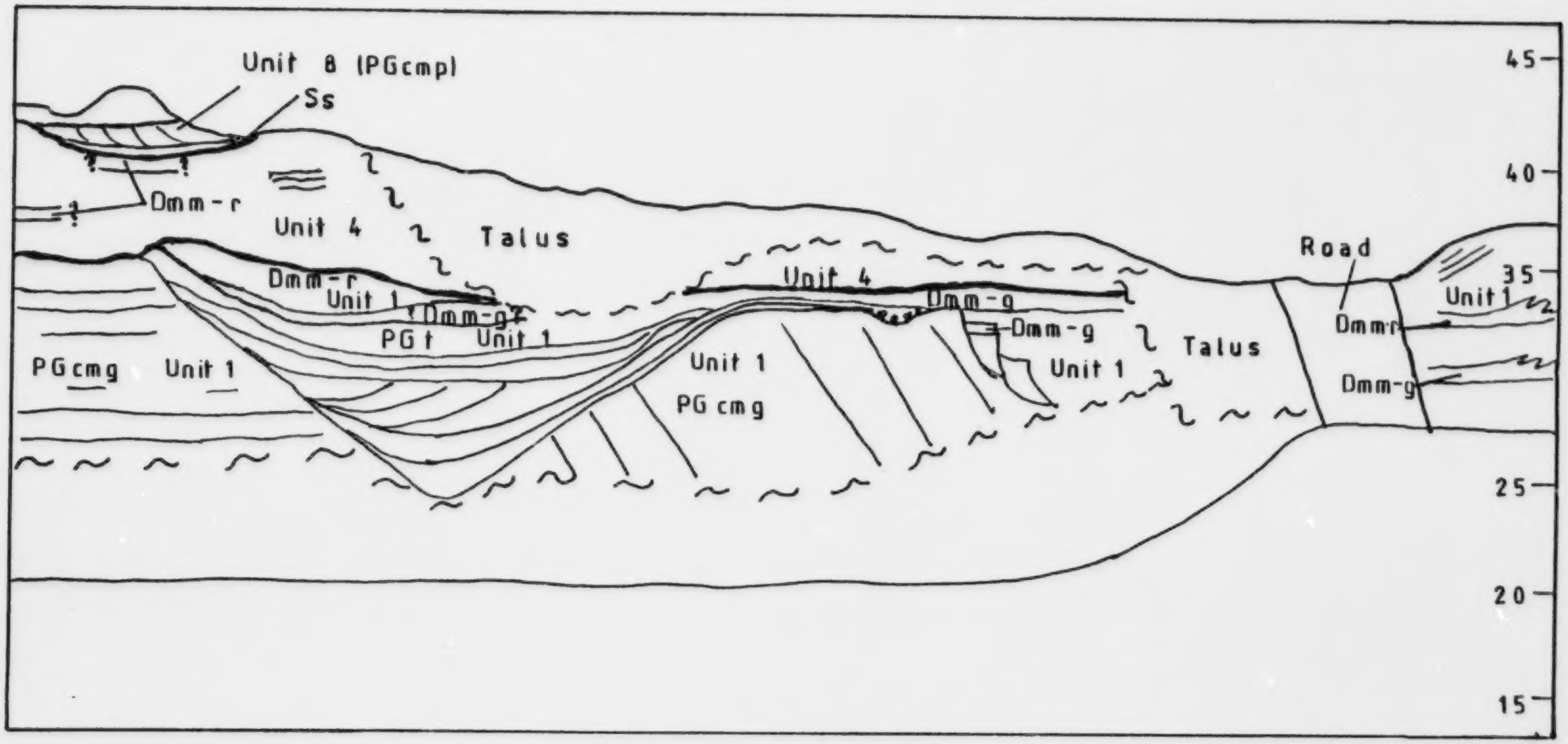


Figure 2.6. Profile of the north wall of the lower and middle lifts of the C&E gravel pit.

is comprised of gravel, diamict, stratified diamict, and sand. These facies are grouped together because of their interfingering relationship (Figure 2.2). Unit 1 is also characterized by large and small normal faults.

The most extensive exposures of Unit 1 are located in the southern portion of the C&E gravel pit. The diamict facies of Unit 1 is infrequently exposed, and comprises less than 10% of the unit. The rest of the unit is predominantly gravel which has been extensively mined and exposed by the pit operators. Figure 2.7, a photograph and photolog, illustrate a portion of Unit 1 as mapped in Figure 2.6.

The diamict facies:

Two massive structureless diamict (Dmm) facies were observed in the deposit: a lower, stiff, greyish-brown, sandy, stony diamict (Dmm-g) and an upper, reddish-brown, fossiliferous, clayey-silt diamict (Dmm-r). These two diamicts were observed in close proximity at two locations (Figure 2.6 and 2.7). The colour contrast between the two is readily apparent in Figure 2.7 (Dmm-r and Dmm-g). Beds of both diamicts appeared repeatedly throughout the exposure.

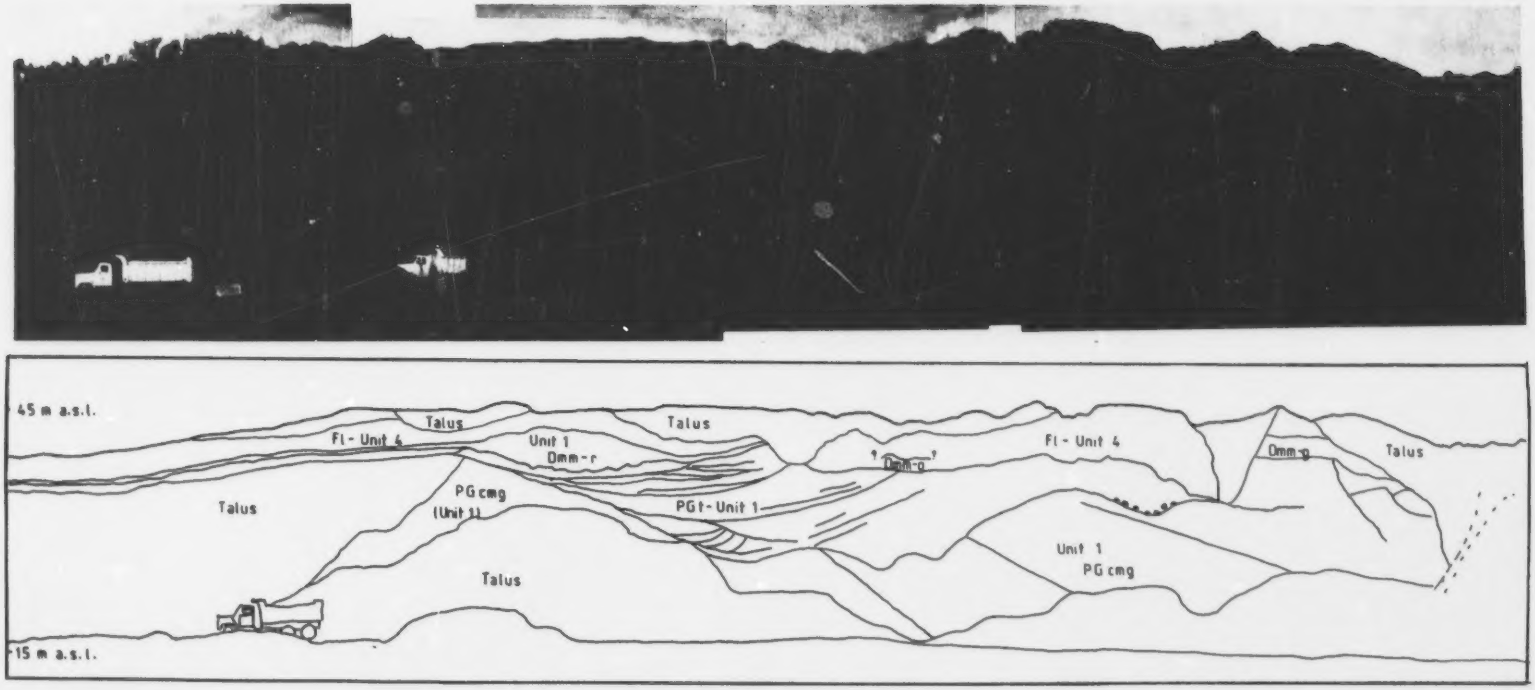


Figure 2.7. Photolog of the north wall of the lower lift of the C&E gravel pit.

1) The greyish-brown diamict facies (Dmm-g):

The lower greyish-brown diamict was exposed at three locations: 1) adjacent to Sheldon Point; 2) on the north wall of the lower C&E pit; and 3) at the base of the highest coastal bluff at the south end of the GO pit. This diamict is competent with angular, cobble to boulder sized clasts. The greyish-brown diamict is occasionally fissile or foliated. Small scale (< 20 cm) thrust faults were observed in the sand and gravel beds below the diamict (Figures 2.8 and 2.9 and Location Dmm-g at right (east) end of Figure 2.7). Thrust faulting can be observed in the sediments, up to 2 m below the diamict (the right side of Figure 2.9 points towards 160°). Faults were observed striking 80° and dipping 35°-60°north and indicate a southward flow. Laminae of silt and/or sand occur infrequently.

At the base of the bluffs adjacent to Sheldon Point, the greyish-brown diamict is exposed (Figure 2.4). (Bedrock is located above sea level at Sheldon Point proper but it is at sea level at the base of the bluffs.) This is the only exposure where the diamict is observed within a few metres of the bedrock. However, the lower contact was covered by beach sediments. The diamict was unconformably overlain by Unit 2.

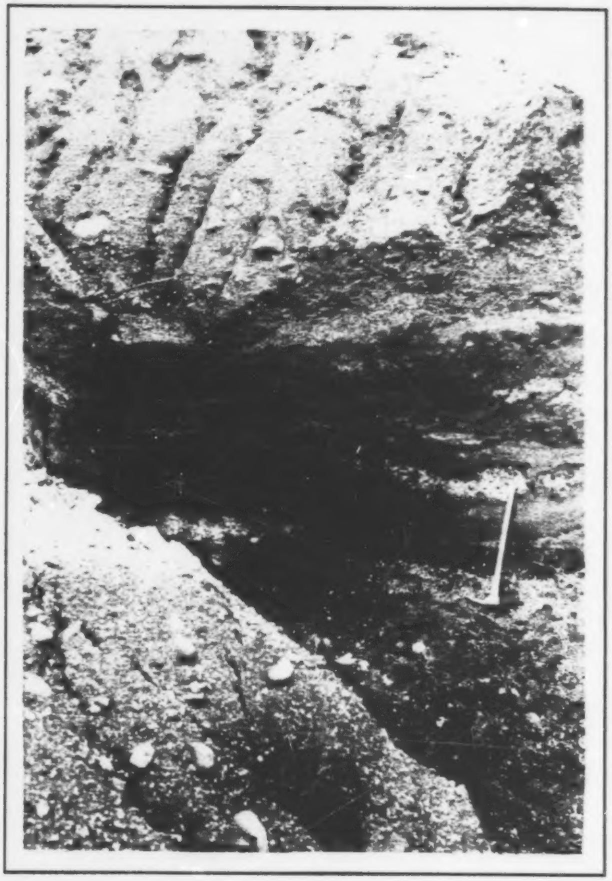


Figure 2.8. Photograph of the greyish-brown diamict overlying gravel. Small-scale thrust faults can be seen in the underlying sediments. A close-up photograph of the small scale deformations can be seen in Figure 2.9. (Figure 2.3 photograph location a)

Figure 2.9. Photograph of small scale thrust faults seen in the sand and gravel beds below the greyish-brown diamict. (Figure 2.3, Photograph location a)

The greyish-brown diamict is exposed in two locations, in the C&E gravel pit, which have been tentatively correlated. At the east end of the exposure, on the crest of the ridge passing through the deposit, a bed of greyish-brown diamict interfingers with the massive gravel facies (Figure 2.10). It also overlies the graded sand facies of Unit 1. In the middle lift of the C&E gravel pit (Figures 2.6 and 2.10), it interfingers with and is overlain by gravel and stratified diamict. At this location, the diamict has unconformable lower and upper contacts. It overlies the coarse, graded sand facies of this unit. The diamict varies in thickness from 0.5 - 2.0 m. In the north wall of the lower lift of the C&E pit (Figures 2.6 and 2.7), the greyish-brown diamict is approximately 1.0 m thick, very stiff, and unconformably overlies trough cross-bedded sand and gravel of this unit.

The third location of this diamict is in the beach bluffs, south of the GO pit. This exposure is at the base of a large ravine and is largely talus covered. It is unconformably overlain by Unit 3.

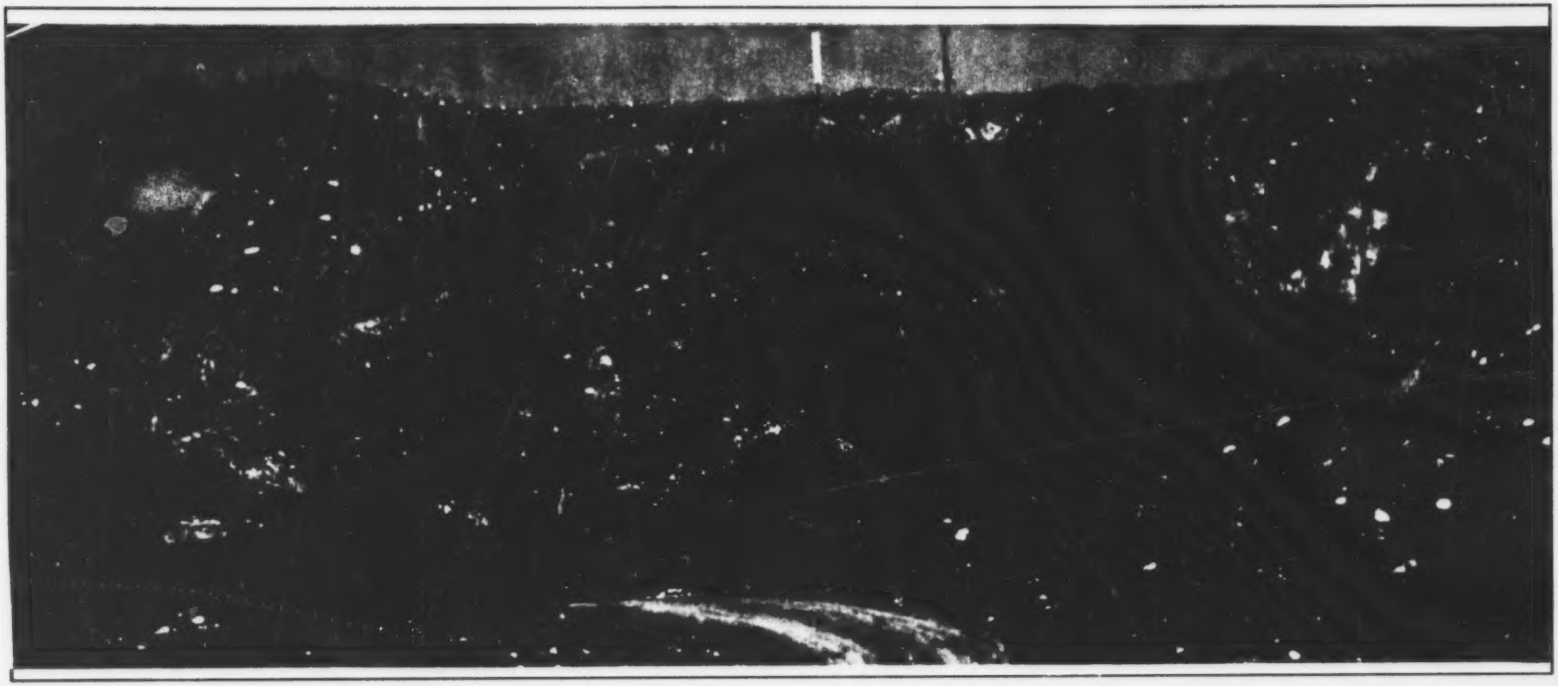


Figure 2.10. Photograph of the middle lift of the C&E gravel pit. At the top of the exposure, the reddish-brown diamict can be seen interfingering and unconformably overlying gravel at the top of the exposure. The greyish-brown diamict unconformably overlies the graded sand seen at the bottom of the eposure near the front-end loader. (See Figure 2.3 for location and orientation of photograph)

2) The reddish-brown diamict facies (Dmm-r)

The reddish-brown diamict was mapped along the north and west wall of the lower lift of the C&E gravel pit (Figures 2.5, 2.6 and 2.7). It was generally less than 0.5 m thick, but ranged up to 3 m. The base of the diamict was undulating, and rested unconformably on sand and gravel (Figure 2.7). It was unconformably overlain by Unit 4 at the lower lift, and interfingered with gravel at the middle lift. Occasionally, bouldery layers appeared, over a few metres, near the base of the diamict. This diamict, in some locations, contained shell material (Hiatella arctica) and the shell content suggests incorporation of seabed material.

Two samples of shell material were recovered from a reddish-brown diamict, at an elevation of 45 m a.s.l. by Rampton et al. (1984). Rampton (personal communication) stated that the samples were obtained in the lower lift, but the exact locations were not recorded. The two carbon-14 dates, obtained from the shell material, gave ages of 13 900 ± 620 yBP (GSC 3354) and 13 100 ± 100 yBP (GSC 3557). H. arctica is an arctic mollusc (Petersen, 1986) and represents the initial colonization of the Sheldon Point area by macrofossils. H. arctica is found in a wide range of water depths (0-1400 m; Petersen, 1986).

The gravel facies:

There are four gravel facies associated with Unit 1: normally-graded gravel, trough cross-bedded sand to gravel, massive and foreset gravel. The Unit 1 gravel facies was only observed in the lower (Figure 2.7) and middle (Figure 2.10) lifts of the C&E gravel pit. The gravel of this unit has abundant large and small scale faults.

1) Normally-graded gravel facies (PGcmg):

Thick, normally-graded gravel beds were observed, dipping approximately 20° east at the base of the lowest lift of the C&E gravel pit (Figures 2.5, 2.6 and 2.7). The gravel is pebble sized and clast to matrix supported. The matrix is composed of sand to fine gravel. The base of this gravel facies was not visible, but the exposed portion is 3-4 m thick. The upper surface of the lower set is unconformable and overlain, on the west end of the exposure, by a northwest dipping set of graded gravel beds. The contact between the northwest and eastward dipping sets is covered by talus, but the exposed portion of this facies is greater than 6 m thick. Individual beds are normally graded at the base and become crudely stratified above. Individual beds average 2 m in thickness.

Large, dip-slip faults were observed in this facies (Figure 2.7 east side) striking 160° and dipping 50° southeast.

2) Trough cross-bedded sand to gravel facies:

The normally graded gravel facies is also unconformably overlain by trough cross-bedded, sand to gravel sized material (Figures 2.6 and 2.7). The trough cross-bedded facies was observed east of the northwest dipping graded beds, in the lower lift of the C&E pit. The set varies in thickness from 4-6 m. The gravel of this facies is pebble sized, and matrix supported (PGt); cobble sized clasts, however, were also observed. The sand varies in grain size from fine to medium and has a reddish-brown colour. The lower bounding surface of each set is erosional and each set cross-cuts the lower sets.

At the lower lift of the C&E pit, the normally graded gravel and trough cross-bedded facies are unconformably overlain by two different facies (Figures 2.6 and 2.7). At the east end of the exposure, the facies are overlain by the greyish-brown diamict. At the west end of the exposure, the trough cross-bedded sand to gravel facies is overlain by the reddish-brown diamict.

3) The massive sandy gravel facies (PGmm):

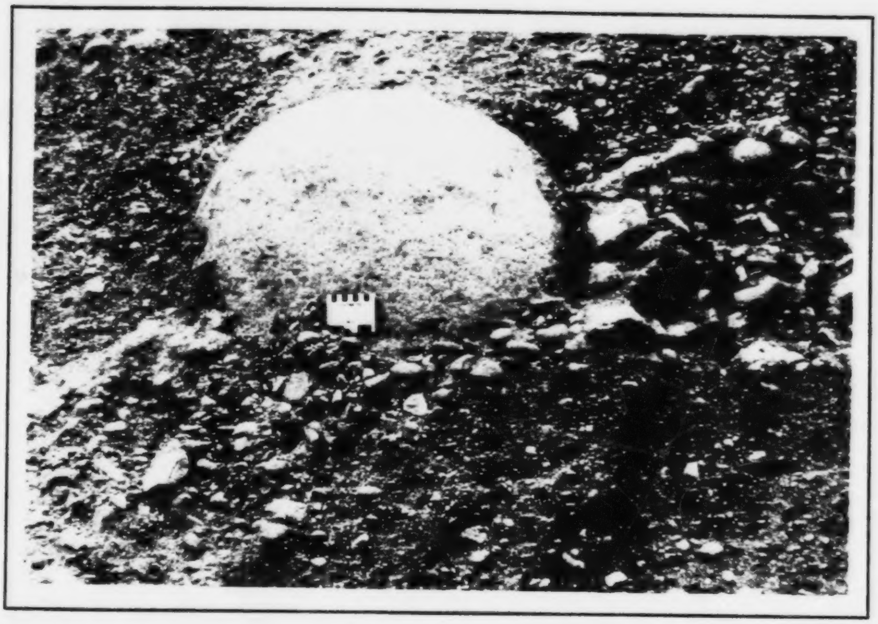
At the middle lift (Figures 2.7 and 2.10), the grey, massive, sandy gravel facies interfingers with and unconformably overlies the greyish-brown diamict. This massive gravel facies is approximately 5 m thick and composed of matrix (sand) supported, pebble sized gravel. The reddish-brown diamict unconformably overlies this facies.

4) The foreset gravel facies (BG-PGcmp)

Along the gravel pit road, between the middle lift and upper lift of the C&E pit, there is a thick (5 - 7 m), pebble to boulder sized, foreset gravel facies. The planar, tabular, foreset beds dip northward (330°) at approximately 30° and have a bed thickness of up to 1 m, but average 0.3 - 0.5 m. The gravel is clast supported at the base, and matrix supported near the top of the beds. Rounded boulders and cobbles were observed at the base of individual beds. Individual beds fine upwards into a muddy gravel (resembling a thin diamict). Articulated H. arctica shells were found, approximately 33 m a.s.l., in a muddy gravel layer and dated at 13 070 ± 370 yBP (GX 13824). The only sedimentary structures observed were cluster bedforms (Brayshaw, 1984), indicating a northward flow direction (Figure 2.11). Balanus crenatus were anchored on the up-current side of the rounded boulder (approx. 28 m a.s.l.). The sample was not dated because there was insufficient material. Hillaire-Marcel (1980) reported that B. crenatus, in samples from the Champlain Sea, is most commonly found in closed basins at generally less than 30 m water depth. Wagner (1970), however, stated that the present distribution is most common between 50 and 100 m and has a second optimum zone of 25-30 m. No faults were observed in this facies.

The stratified diamict facies

There are two stratified diamict facies: greyish brown and reddish-brown. The reddish-brown diamict is stratigraphically higher than the greyish-brown diamict. The two facies were observed in the lower and middle lifts of the C&E pit and in the bluffs adjacent to Sheldon Point.



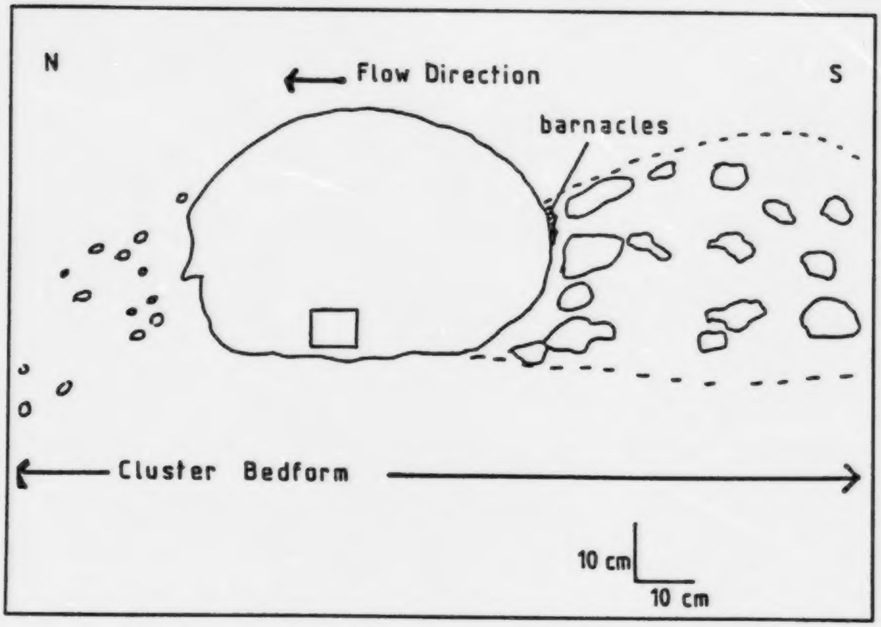


Figure 2.11. Cluster bedforms observed in the foreset gravel facies of Unit 1 at the middle lift of the C&E gravel pit. (Figure 2.3 photographic location b)

1) The grey, stratified diamict (Dms-g)

The grey, stratified diamict is composed of grey, sandy, muddy gravel layers. It occurs at the middle lift of the C&E pit and in the beach bluffs adjacent to Sheldon Point.

At the C&E location, the grey, stratified diamict unconformably overlies the massive greyish-brown diamict at the base. The grey, stratified diamict unconformably underlies the massive gravel facies above. The beds dip north at approximately 30°. The observed bed thickness was 0.1 - 0.3 m. The stratified diamict facies is approximately 2 m thick at this location.

At the second location, adjacent to Sheldon Point, the stratified greyish-brown diamict is approximately 0.5 m thick and is interbedded with thin layers of medium-grained sand. The stratified diamict was seen to conformably overlie the massive greyish-brown diamict and unconformably underlie Unit 2.

2) The reddish-brown, stratified diamict facies

The stratified, reddish-brown diamict (Dms-r) was observed at the lower and middle lifts of the C&E gravel pit. The beds are generally less than 0.3 m thick.

The sand facies

Two sand facies were observed in the middle lift of the C&E gravel pit (Figure 2.10). One is a normally graded sand and the other shows cross-bedding.

1) The normally graded sand facies (Sg)

The normally graded sand is grey and coarse-grained, and the beds range in thickness from 0.1 - 0.5 m. Larger granule to pebble sized clasts, included at the base, have an a-axis alignment parallel to flow. The facies is composed of stacks of graded beds (Figure 2.12). Stringers of finer grained sand were common between beds throughout this facies. This facies is intensely faulted and unconformably overlain by the greyish-brown diamict. The diamict has an undulating erosive base.

2) The cross-bedded sand facies (St)

The cross-bedded sand is reddish-brown and medium to fine grained. The sand is occasionally cross-

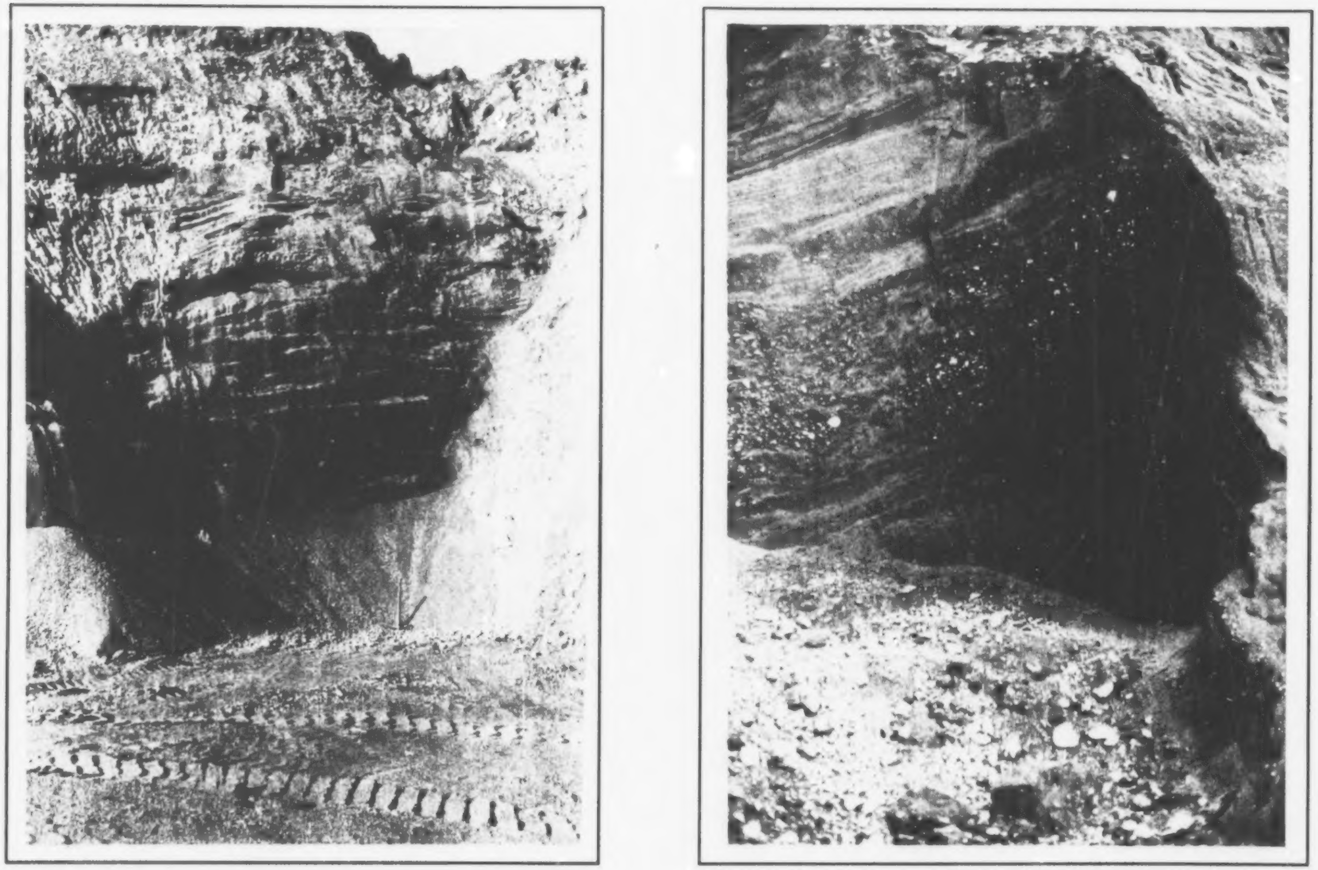


Figure 2.12. Photographs of the graded sand facies of Unit 1. Left photograph displays the stacks of graded sand and the right photograph displays the fine sand stringer between beds. (Figure 2.3 photograph location c)

stratified with matrix supported, pebble sized gravel. The beds dip less than 20° northwards. The beds are thicker and coarser at the base. It is faulted (Figure 2.13) and in some locations small dykes of reddish-brown diamict were observed. This facies was overlain by the massive gravel facies and the reddish-brown diamict.

UNIT 2

Unit 2 is divided into two facies: normally graded sand (Sg) and stratified sand (Ss). The graded sand was observed in the east wall of the lower lift of the C&E gravel pit, and adjacent to Sheldon Point (Figures 2.4, 2.14, and 2.15). The stratified sand was observed in the east wall of the lower C&E gravel pit and could be traced to the beach bluffs (Figure 2.16). Unit 2 was only observed on the south side of the Sheldon Point deposit (Figure 2.2). This unit was not observed interfingering with any other facies or units. No faults were observed in this facies.

1) The graded sand facies (Sg)

The graded sand facies is composed of beds of graded sand superimposed on one another. The sand is

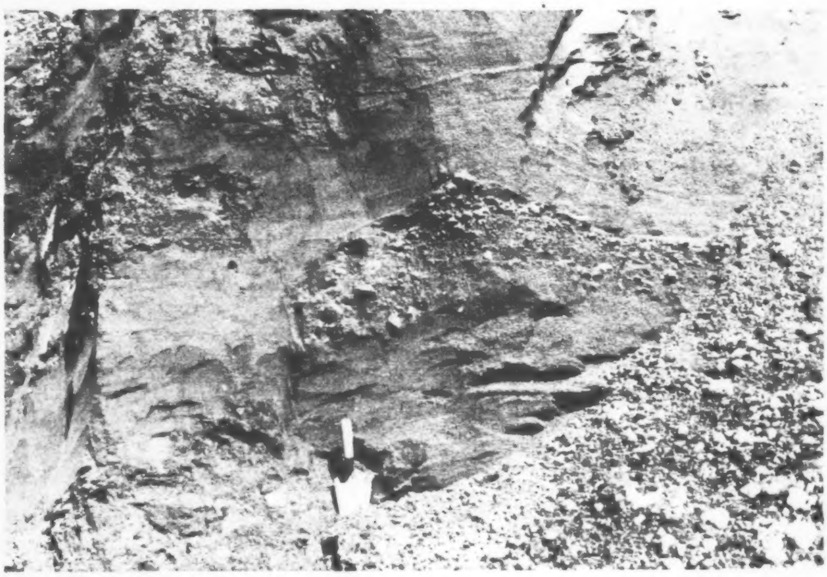


Figure 2.13. Photograph of the stratified sand of Unit 1 and the step faults observed in this facies. (Figure 2.3 photographic location c)

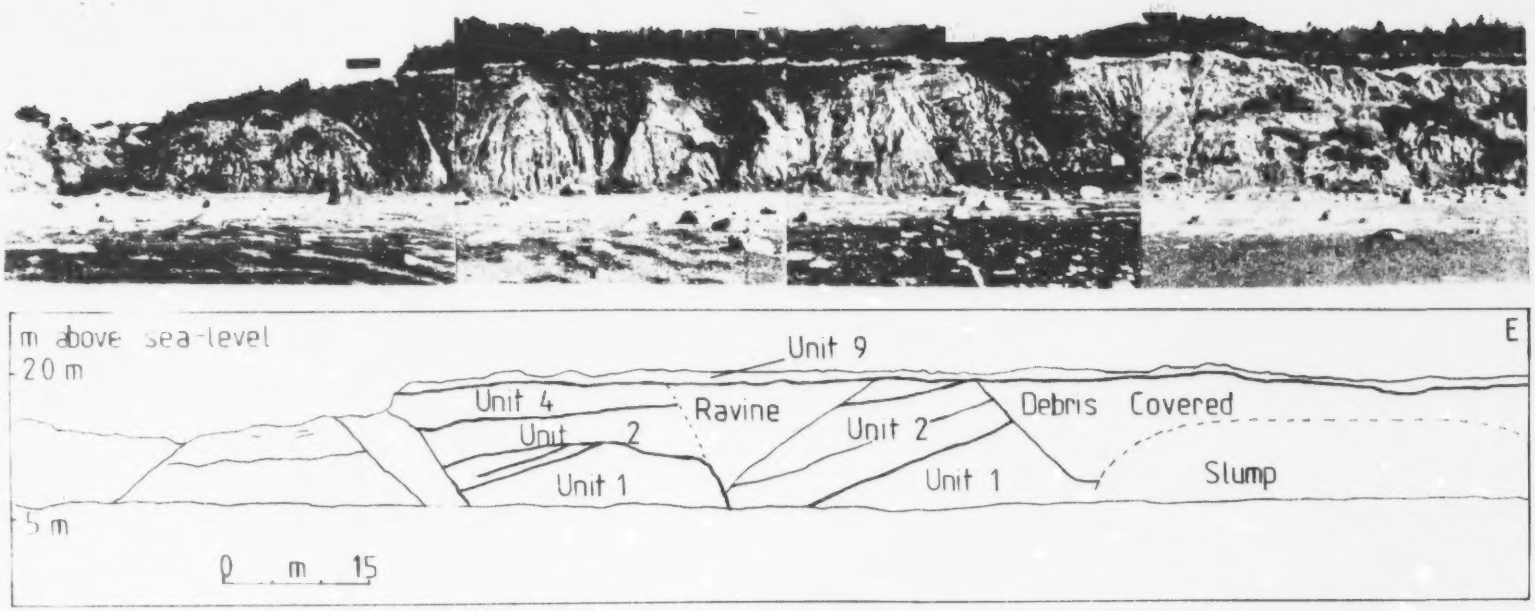


Figure 2.14. Photolog of the eastern end of the beach adjacent to Sheldon Point. Note the sharp contact between Unit 2 and the greyish-brown diamict of Unit 1.

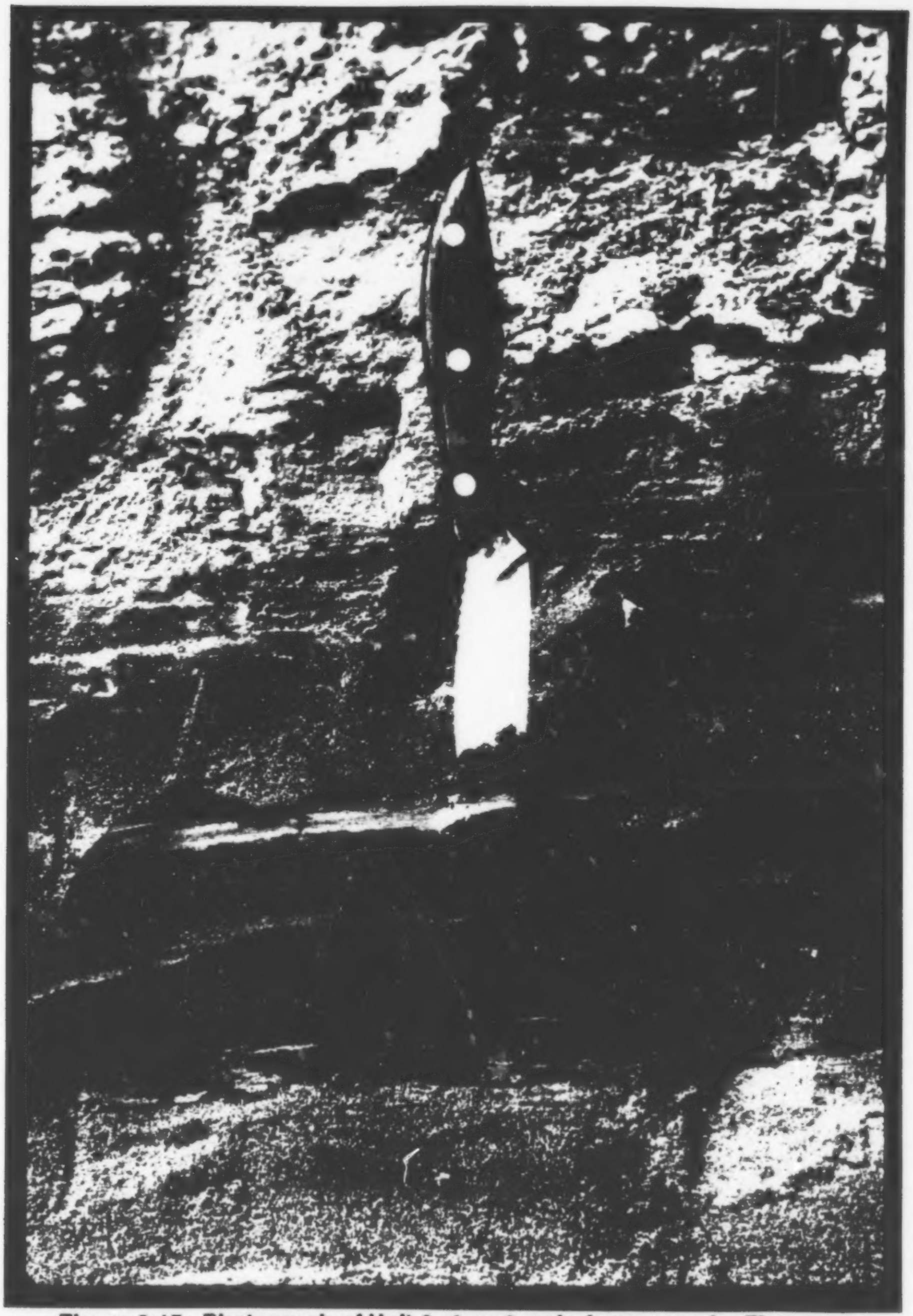


Figure 2.15. Photograph of Unit 2 at east end of exposure in Figure 2.14. Note the change of colour with the change of grain size. (Figure 2.3 Photograph location d)

medium to coarse at the base and grades upwards into a fine sand. In the vicinity of Sheldon Point, the normally graded sand facies unconformably overlies the greyish-brown diamict of Unit 1 (Figure 2.14). The sand is well sorted, and devoid of pebbles or cobbles. The lower contact is sharply defined (Figure 2.14). The extent and shape of the sand layer could not be determined because present day slumping occurs in this area. The sand facies is 6-7 m thick and dips southward (150°). The upper boundary is transitional, becoming thinner and rhythmically interbedded with the overlying Unit 4. There is a marked change in colour with the change in grain size (Figure 2.15). At the base of the section, the sand is medium grained and grey in colour. Higher in the section the sand fines abruptly and changes to a reddish-brown colour.

The second location of this facies, in the east wall of the lower C&E pit, is poorly exposed. The beds dip 30-35° southward (160°). Climbing ripples and dewatering structures were observed at this site.

2) The stratified sand facies

The stratified sand facies overlies the graded sand facies in the east wall of the lower lift of the C&E pit. The stratified sand facies contains dispersed boulders and cobbles. This wall of the pit has not been worked for many years and, therefore, was poorly exposed. The best exposure of this facies is located at the beach bluffs east of the C&E gravel pit. There the deposit is 20 - 25 m thick (Figure 2.16). At this site the stratified sand is conformably overlain by Unit 4. The stratified sand is medium-brown and dips 30-35° southward (approximately 160°). The individual beds are 0.3 - 0.5 m thick.

UNIT 3

Unit 3 is a matrix supported gravel facies (BGmg-PGmg) containing a minor sand component. The characteristic feature of this unit is the U-shaped channel form (Figure 2.2). This facies was observed in the beach bluffs (Figure 2.17) south of the GO pit, and in the west wall of the lower lift of the C&E pit (Figure 2.5).

In Figure 2.17, the apparently wide troughs are clearly visible. They have planed-off upper surfaces and broad U-shapes. The troughs are stacked on top of one another, and their apparent widths and depths decrease with elevation. The apparent width of these channels is 80 - 100 m. The channels trend at an oblique angle (approximately 60 °) to the bluffs and the

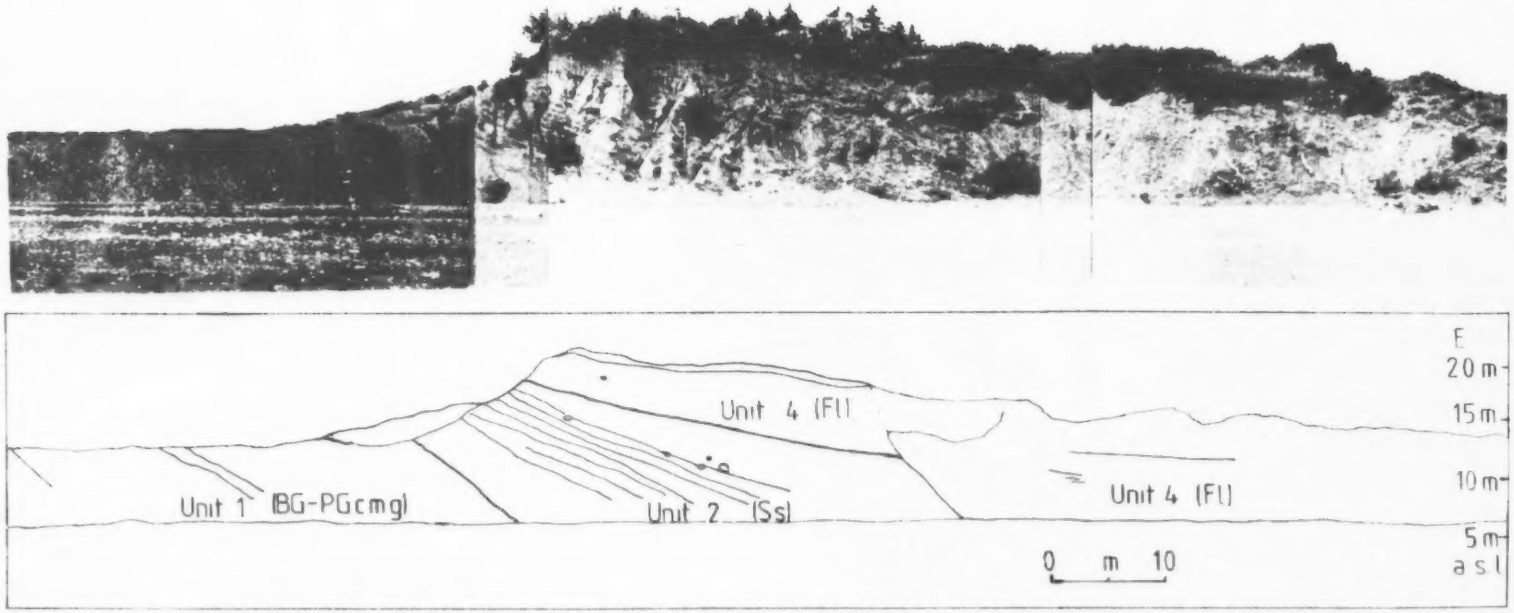


Figure 2.16. Photolog of the beach bluffs east of the C&E gravel pit. Note the large boulders indluded in the stratified sand of Unit 2.

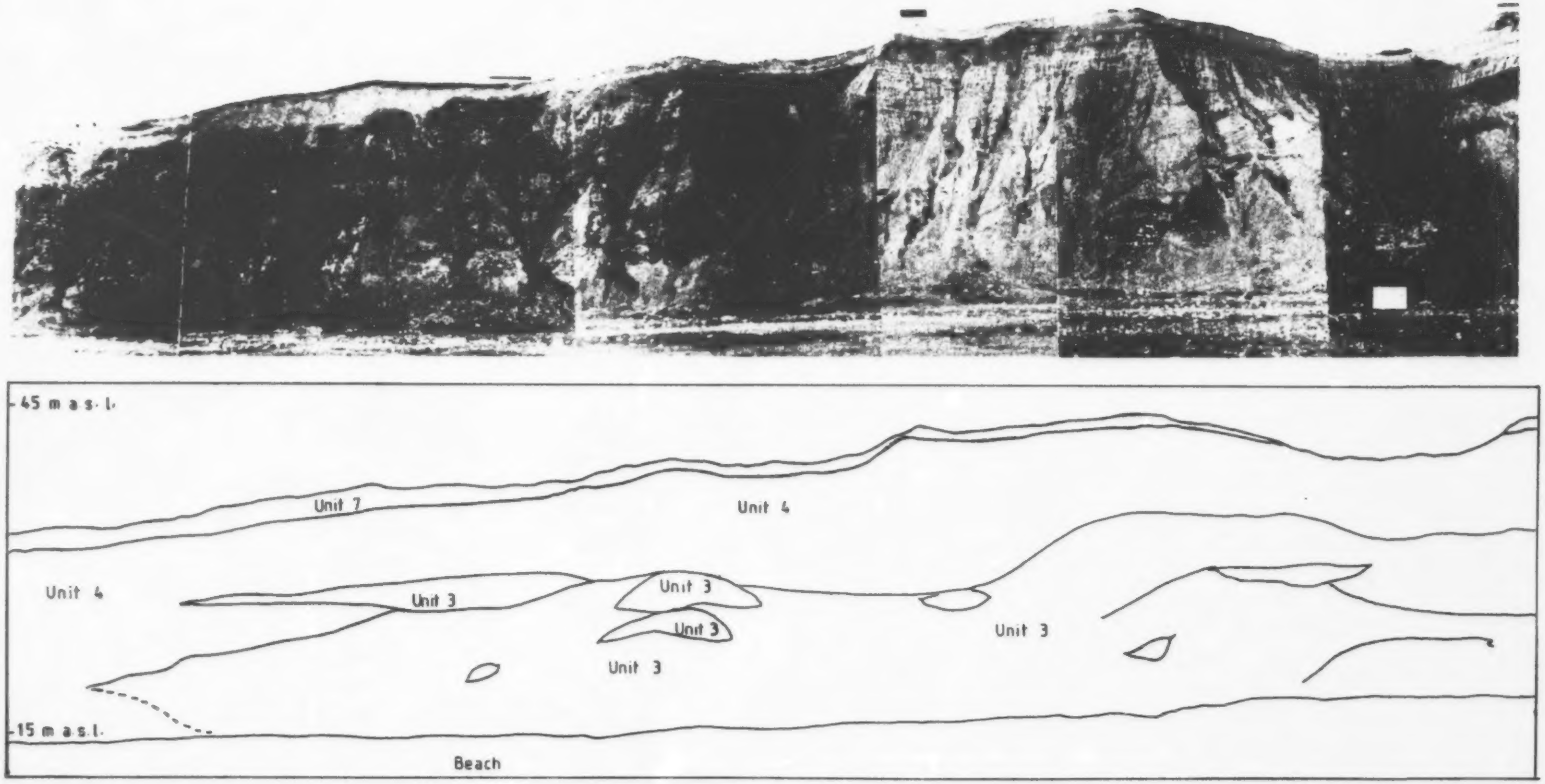


Figure 2.17. Photolog of the beach bluffs south of the GO pit. Note the large trough shaped channels with a truncated upper surface.

true width, however, is 40 - 50 m (width= apparent width x cos 60).

At the base of this section the lowest trough unconformably overlies a small outcrop of the greyish-brown diamict of Unit 1. Within the trough the gravel is massive with crude imbrication at the base. Higher in the section, the gravel becomes normally graded and crudely stratified (Figure 2.18). Further up, the gravel becomes stratified and occasionally cross-bedded. Some of the beds dip steeply (up to 50°) northward (340°). In one instance an entire bed is displaced and resembles a slumped block. Thin (30 cm), graded sand layers were observed and could be traced laterally 20 - 30 m. This lowest trough is approximately 4 m thick, from top to bottom, at the deepest point in the trough.

The stratigraphically higher U-shaped channels gradually shoal and are finer grained (Figures 2.4 and 2.17). The highest channels are filled with a muddy gravel that resembles a diamict. The stratigraphically highest trough is approximately 1 m thick. The lower troughs are superimposed on each other but the upper troughs are interbedded with Unit 4 above (Figure 2.17).

The second location of this facies is in the west wall of the lower lift of the C&E pit (Figure 2.5). This asymmetric channel is 3 m deep and 8 - 10 m wide. It contains sandy gravel with abundant cobbles,

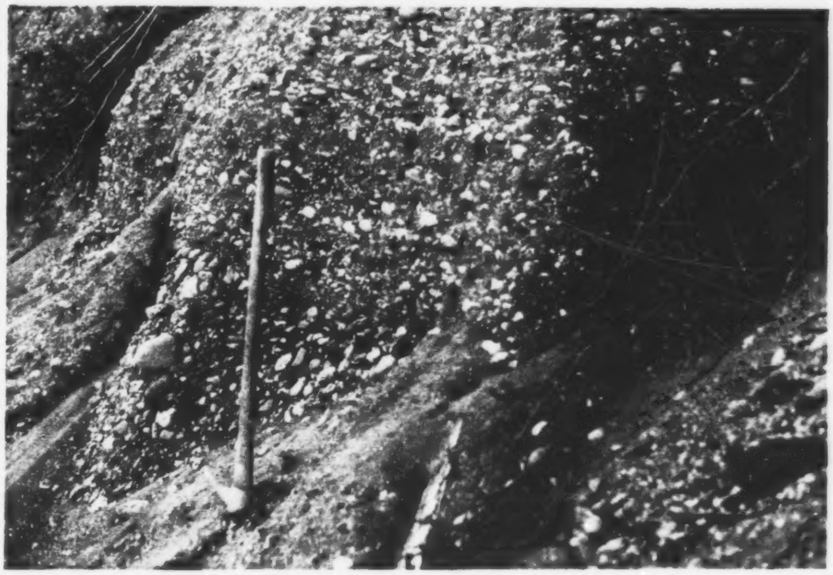


Figure 2.18. Photograph of the gravel at the base of Unit 3 exposed in the bluffs south of the GO gravel pit. The gravel changes from massive to weakly stratified. (Figure 2.3, Photograph location e)

boulders, and "floating" blocks of stratified, sandy sediments. The stratification is oriented in a variety of directions (Figure 2.19). The sediments within the trough are quite variable and chaotic; no sedimentary structures, such as bedding, imbrication, or grading, could be identified. No shell material was found within this unit. Unit 3, however, interfingers with Unit 4, which has been dated.

UNIT 4

Unit 4 is composed of finely stratified to laminated clay, silt (Fl), graded sand, and muddy gravel (Fd) (Figure 2.20). This unit is best exposed in the beach bluffs adjacent to Saints Rest Beach (Figures 2.4 and 2.17; dipping northward) and between the C&E pit and Sheldon Point (Figures 2.14 and 2.16; dipping southward). It was also observed in the lower lift of the C&E gravel pit (Figures 2.5, 2.6, & 2.7). The unit interfingers with and overlies the trough-shaped channels of Unit 3, and fines as the distance increases laterally and vertically from Unit 3 (Figure 2.17). The maximum overall thickness of the deposit is 20 m. The highest occurrence of this unit is found approximately 35 m a.s.l.

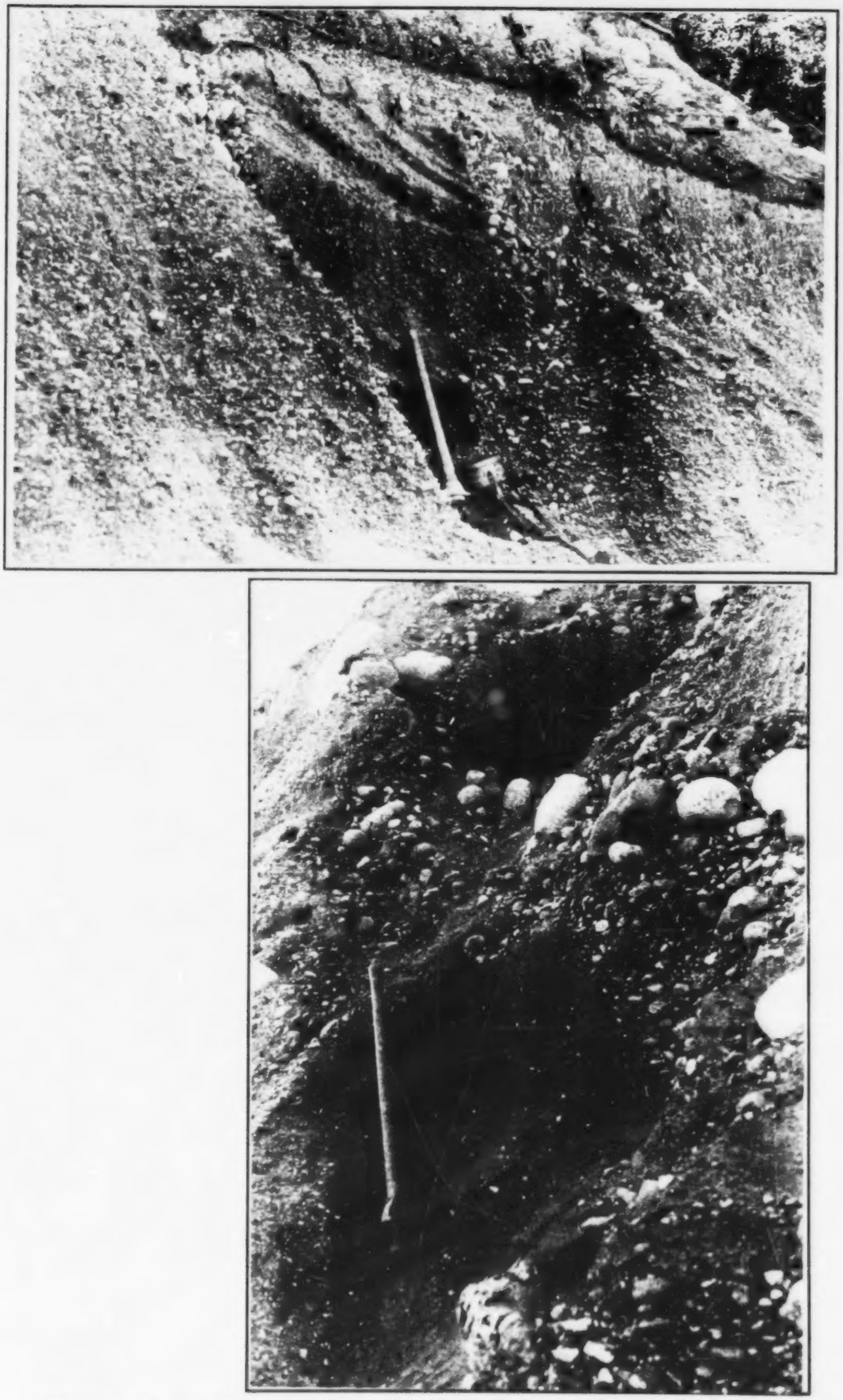


Figure 2.19. Photograph of the "floating blocks" of sediment in the channel fill of Unit 3 exposed in the west wall of the lower lift of the C&E gravel pit. (Figure 2.3 photograph location f)

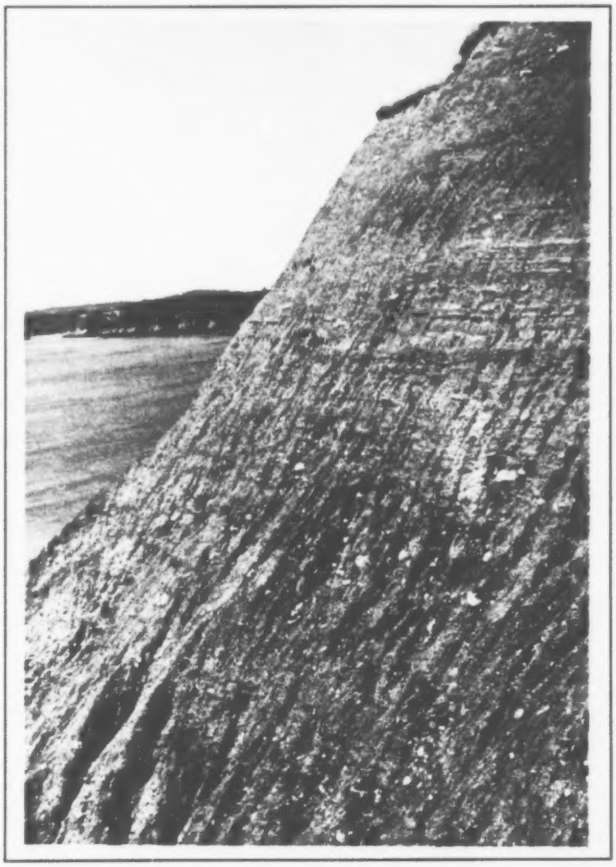


Figure 2.20. Photograph of Unit 4 located near the top of the photolog illustrated in Figure 2.17. Note the bending of the stratifications around cobbles in the stratified clays and muddy gravel of Unit 4. (Figure 2.3 Photograph location g)

The upper and lower contacts of the laminations are sharp. Occasional pebble and granule size materials were found in the clay, sand, and silt laminations. The muddy gravel beds were less than 0.2 m thick.

At the top of this unit the clay graded into a fine grained, graded sand (Figure 2.21). The sands are often rippled, cross-laminated and draped with mud. Occasional drop stones were seen throughout the facies. Unit 4 is conformably overlain by Unit 5.

Gadd (1973) and Lee (in Walton *et al*., 1961) collected and dated three different shell samples from this facies: two from the east end of the beach (13 000 ± 170 yBP (GSC 1340) and 13 200 ± 200 yBP (GSC 965)), and one from the west end of the beach (13 325 ± 500 yBP (I(GSC) 7)). The identified species of shells from all three samples were as follows: *Portlandia arctica*, *Macoma calcarea* (Ghelin), *Mya truncata*, *H. arctica*, *Macoma balthica* (Linne), *Balanus sp.*, and *Serripes groenlandicus* (Bruguiere) (Rampton *et al*., 1984; Gadd, 1973; Lowdon and Blake, 1970; Walton *et al*., 1961.).

P. arctica is generally found in water depths greater than 40 m, however the other species are found in variable, shallow water depths (<50 m) (Petersen, 1986). All species tolerate low levels of salinity.

Figure 2.21. Photograph of the upper portion of Unit 4. Note that the clays and sand are sorted and there are few pebbles. The muddy gravel layers are absent. (Figure 2.3 Photograph location h)

Gadd (1973) (p.17 and 18) reported the following ostracods (identified by J.E. Hazel) from the same samples as above: (C=common, R=rare)

> ostracods: Leptocythere machesneyi (C) (Brady and Crosskey, 1871), Normanicythere concinella (C) (Swain, 1963) "Acanthocythereis" cuspidata, (R) (Brady and Crosskey, 1871), Cytherura granulosa (R) (Brady and Crosskey, 1871), Cytheropteron nodosum, (R) (Brady, 1868), Paradoxostoma cf. P. variable (R) (Baird, 1850) and Cytheropteron pyramidale (R) (Brady, 1868)) which were interpreted to represent deposition in quite shallow, very cold (frigid-subfrigid water) waters of normal salinity.

Welsted (1976 p.381) reported the following foraminifera (identified by F.J.E. Wagner) from samples collected proximal to the above dated shell samples:

> Quinqueloculina sp., Elphidium excavatum forma clavatum (=Elphidium incertum clavatum Welsted, 1976), and Islandiella islandica, which indicate cold water marine conditions.

Five samples of 20 cc each were collected from this unit for foraminiferal analysis completed by D.B. Scott. Three samples were collected from each of the clay, silt, and muddy gravel layers at one location. All three samples contained between 6 and 10 specimens of the following 4 species: *Elphidium excavatum*, *Cassidulina reniforme*, *Elphidium bartletti*, and *Buccella frigida*. One sample was obtained from the faintly laminated clay, stratigraphically higher in the same section. This sample contained 50 specimens and was dominated by *C. reniforme*. *Elphidium excavatum f. clavata* was also present. The last sample was from a shelly, black, mottled clay horizon near the top of this unit, approximately 1 m below the upper unconformity. There were 7 specimens which included 3 specimen of *E. excavatum f. clavata*, and one each of *C. reniforme*, *Patellina corrugata*, *Glabratella wrightii*, and *Quinqueloculina seminulum*. Scott (personal communication) interprets these assemblages as representing ice-margin conditions.

UNIT 5

Unit 5 is a reddish-brown, soft, laminated to massive, fossiliferous clay facies containing rare granule or pebble sized clasts. It was observed at one location: the base of the lowest lift of the GO pit. At this site, the clay is often contorted, with steep boundaries that resemble normal faults. Figure 2.2 illustrates its spatial distribution. Material from the overlying unit, Unit 6, is incorporated into Unit 5 at one location and appeared normally faulted. Small scale deformations, observed at one small location, resemble thrust faults (striking 040°-070° and dipping 30°-40° northwest) and indicate disruption by an overriding mass or a compressional force, originating from the northwest (Figure 2.22, the right side of the photograph points 150°). The lower boundary of this unit was not visible. Borehole data, made available by the operators of the GO pit, indicate that this clay is frequently greater than 10 m thick and is underlain by Unit 4. The upper contact is unconformably overlain in one area by Unit 6. In other areas this unit is conformably overlain by Unit 7.

The shells included in the clay are Mya pseudoarenaria, Spisula polynyma, and Mactomeris (either M. polynyma or M. ovalis) (F.E. Cole, personal communication). The shells were articulated but cracked and compressed in situ. F.E. Cole (personal communication) indicated that the fracturing occurred after deposition. M. pseudoarenaria has an arctic distribution. S. polynyma is found in the present Bay of Fundy and has a range from the Arctic to Rhode Island. They are both considered "shelf" species and are found in water depths of less than 100 m. There was insufficient material to obtain a C-14 date for this

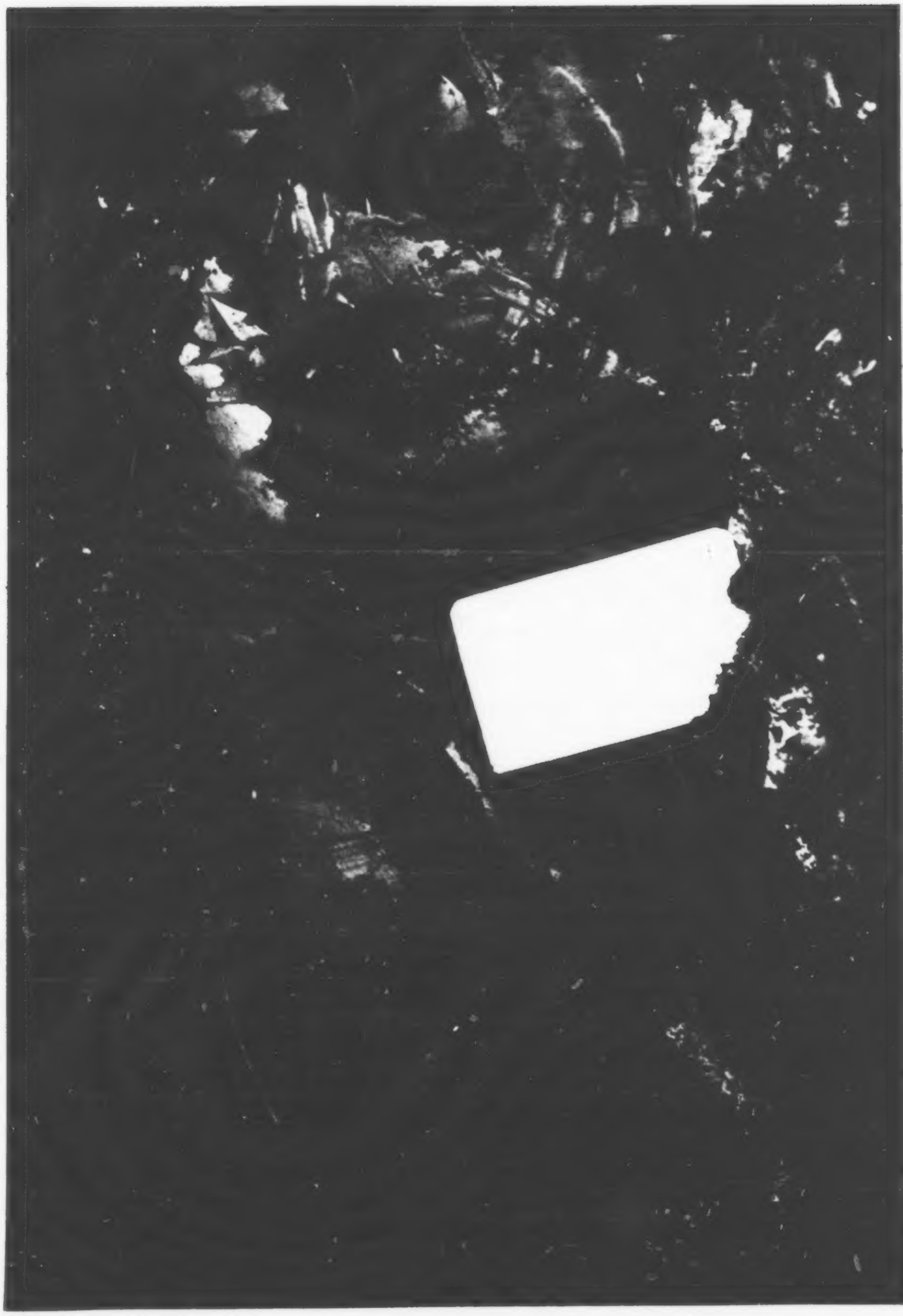


Figure 2.22. Photograph of the deformations within Unit 5. (Figure 2.3 Photograph location I)

unit. The youngest C-14 date obtained from the unit below is 13 000 ± 170 yBP (GSC 1340). The C-14 date obtained from Unit 6, above, is 12 650 ± 175 yBP (GX 12971).

UNIT 6

Unit 6 was observed in only one location, the lowest lift of the GO pit illustrated in Figure 2.2. The sandy, pebble-sized gravel is matrix supported and stratified (PGms). The individual strata are coarse at the base, and fine upward to sand (Figures 2.23 and 2.24). This unit has a gently curving upper surface and individual strata thicken towards the central portion of the deposit. The lower contact is buried and the upper contact is unconformable with the overlying unit, Unit 7 (Figure 2.25). Two large beds (approximately 4 m thick) were observed in this unit bounded by an unconformable surface. The lower bed can be seen in the lower left corner of Figure 2.23. Large scale, southward dipping faults were observed (Figure 2.23) in this unit. The faults strike 150° and dip 50° to 60°.

The lower bed of this unit was barren of macrofossils. The upper bed, however, had abundant *Mytilus edulis* shells (Figure 2.24) throughout. The

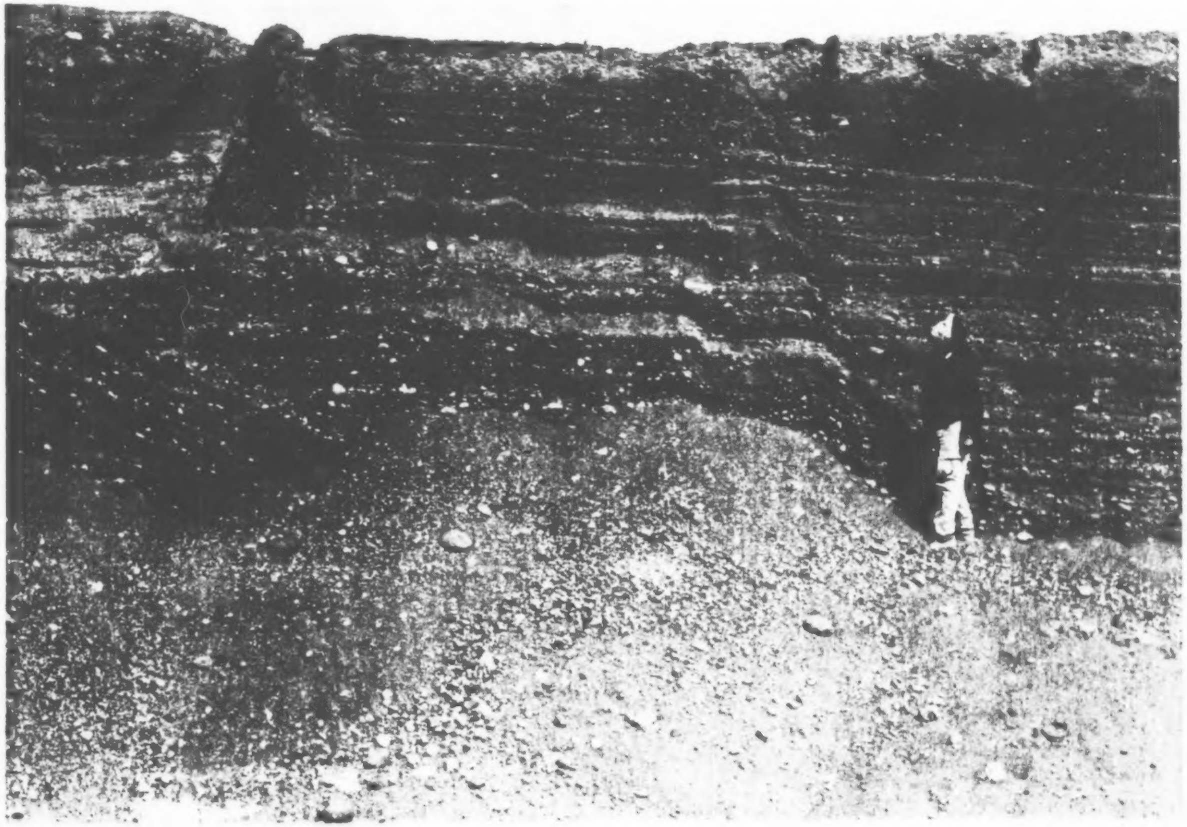


Figure 2.23. Photograph of Unit 6 and the large faults within this unit. The lower barren bed can be seen in the lower left corner of the photograph. (Figure 2.3 Photograph location j)

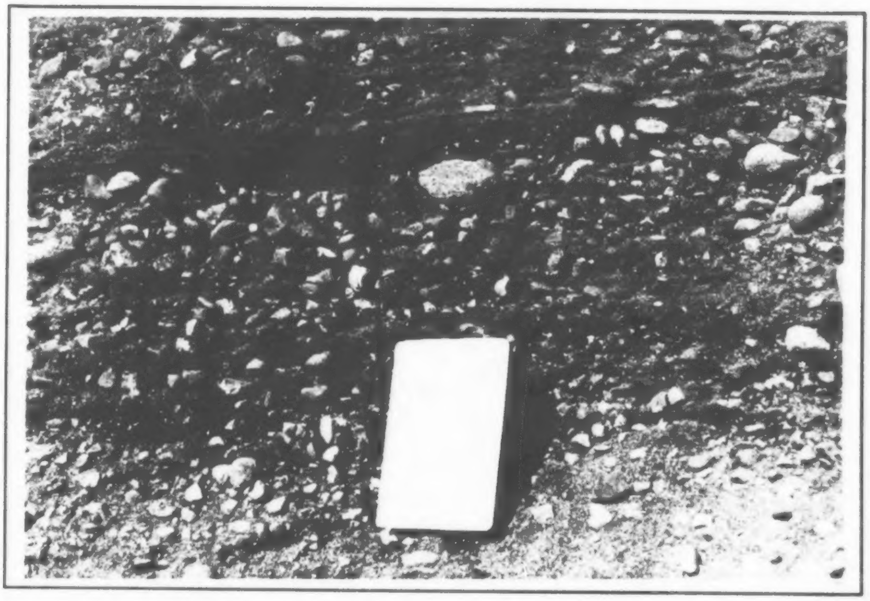


Figure 2.24. Photograph of the gravel and Mytilus edulis in Unit 6. Notice the association of the shells in the upper left corner with a small pebble cluster. (Figure 2.3 Photograph location j)

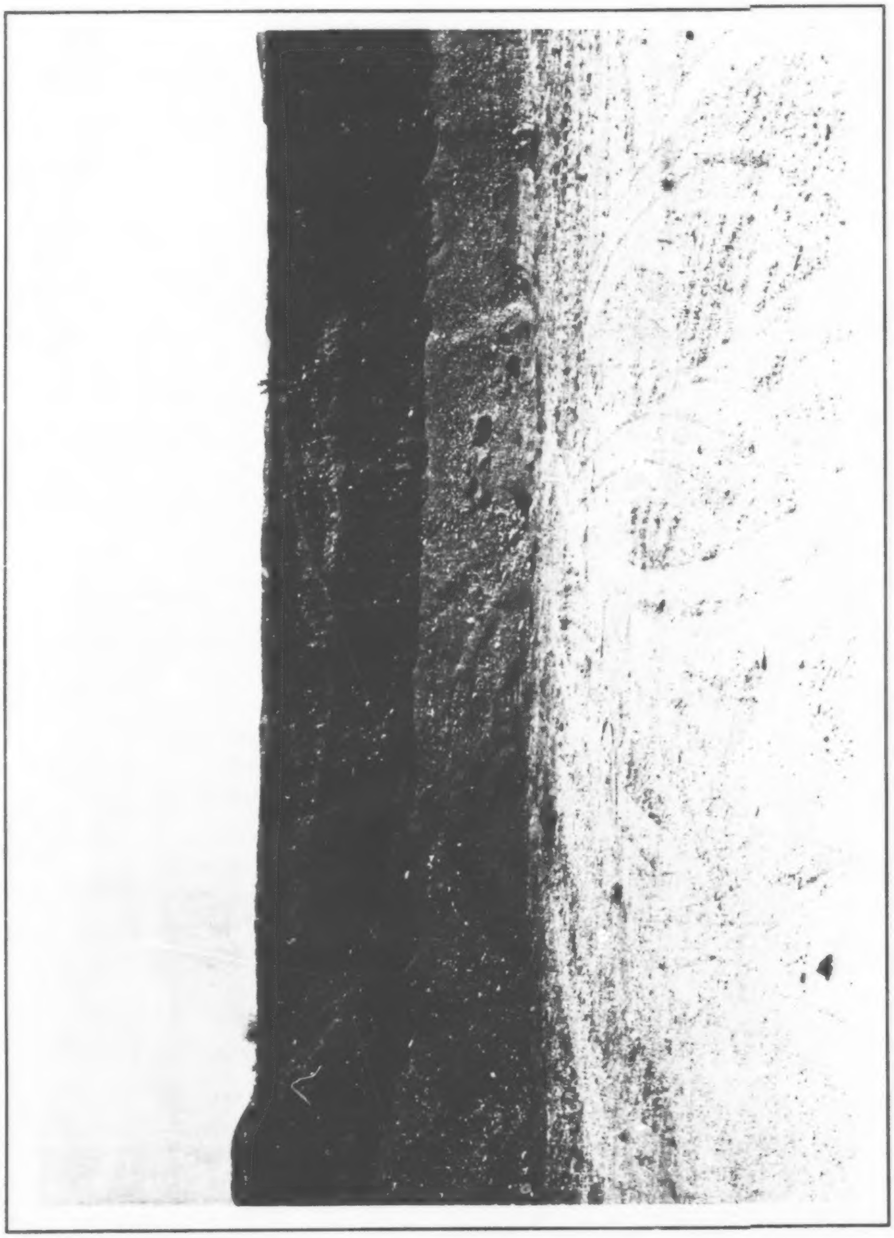


Figure 2.25. Photograph of Unit 7 unconformably overlying Unit 6 in the GO gravel pit. (Figure 2.3 Photograph location k)

shells were often found on the stoss side of a small cluster of cobbles (Figure 2.24). M. edulis is a shallow water (less than 30 m) bivalve. The shells are thin-walled, dwarf, articulated, and well preserved. The fact that the shells are thin walled and dwarf indicates cold, brackish conditions (Wagner, 1970). These shells were observed between 20 and 25 m a.s.l. and were dated at 12 650 ± 175 yBP (GX 12971).

UNIT 7

Unit 7 is a grey matrix supported to open work gravel with a minor sand and mud component. It is dominated by cross-set bedding. This unit was observed in the lower and middle lifts of the GO pit (Figures 2.25 and 2.26). The lower contact is unconformable where it overlies Unit 6 (Figure 2.25). However, at the lower contact with Unit 5 is a facies of interbedded coarse sand and mud resembling bottomset beds (Figure 2.26). The contact between Unit 7 and Unit 8 was not observed. Higher in the section, the interbedded mud and gravel passes into cross-bedded sandy gravel with occasional muddy beds. The upper contact was not visible as it had been entirely planed off during gravel extraction. The thickness of the cross-beds is generally less than 2 m. The dip and orientation of the

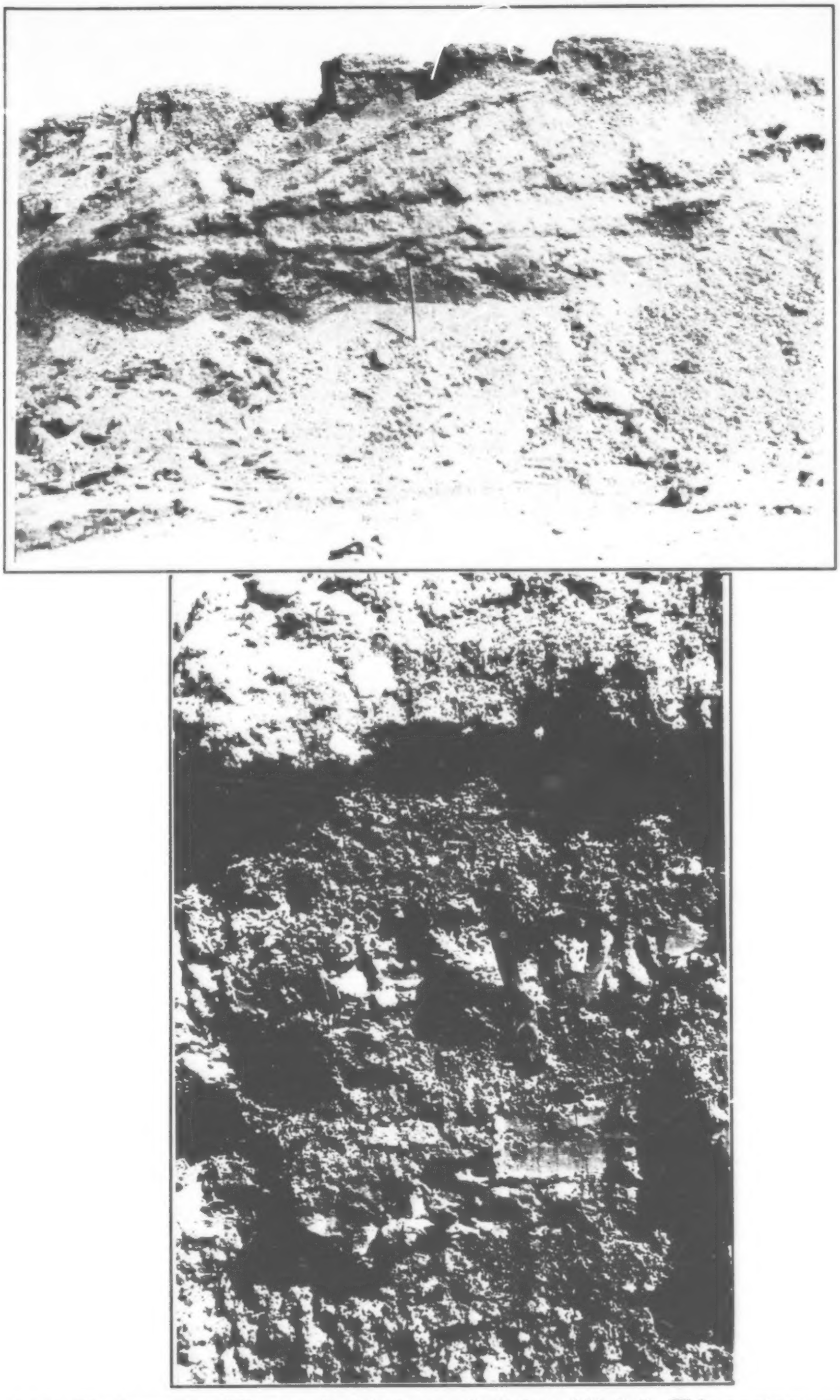


Figure 2.26. Photograph of the contact between Unit 5 and Unit 7. This contact resemble bottomset beds. (Figure 2.3 Photograph location I).

cross-set beds is variable, and the unit appears to have infilled underlying depressions and to have smoothed the sea bed. The stratifications are 10-20 cm thick. No shells were recovered.

UNIT 8

Unit 8 is composed of large, planar-tabular foreset beds (Figure 2.27). The gravel is pebble sized and is clast to matrix (granules to sand sized) supported (PGcmp). This facies was observed in the upper lifts of both the GO and C&E gravel pits, and across the road in an abandoned gravel pit. These foresets dip approximately 15°, and fine northward (350°). The unit is 3-5 m thick and individual strata vary in thickness from 30 cm to 50 cm. These large foreset beds form a lobe-shaped deposit immediately north of Sheldon Point. This gravel facies has been entirely extracted except along the property line between the two pits. Aerial photographs (not illustrated), taken during the late fifties and early sixties, show that Unit 8 was one of the first units quarried.

At the base of this unit, in the southwest corner of the upper lift of the C&E pit, articulated, whole shells of H. arctica, M. pseudoarenaria and Buccinum tenue (Grey) were sampled. The H. arctica shells were

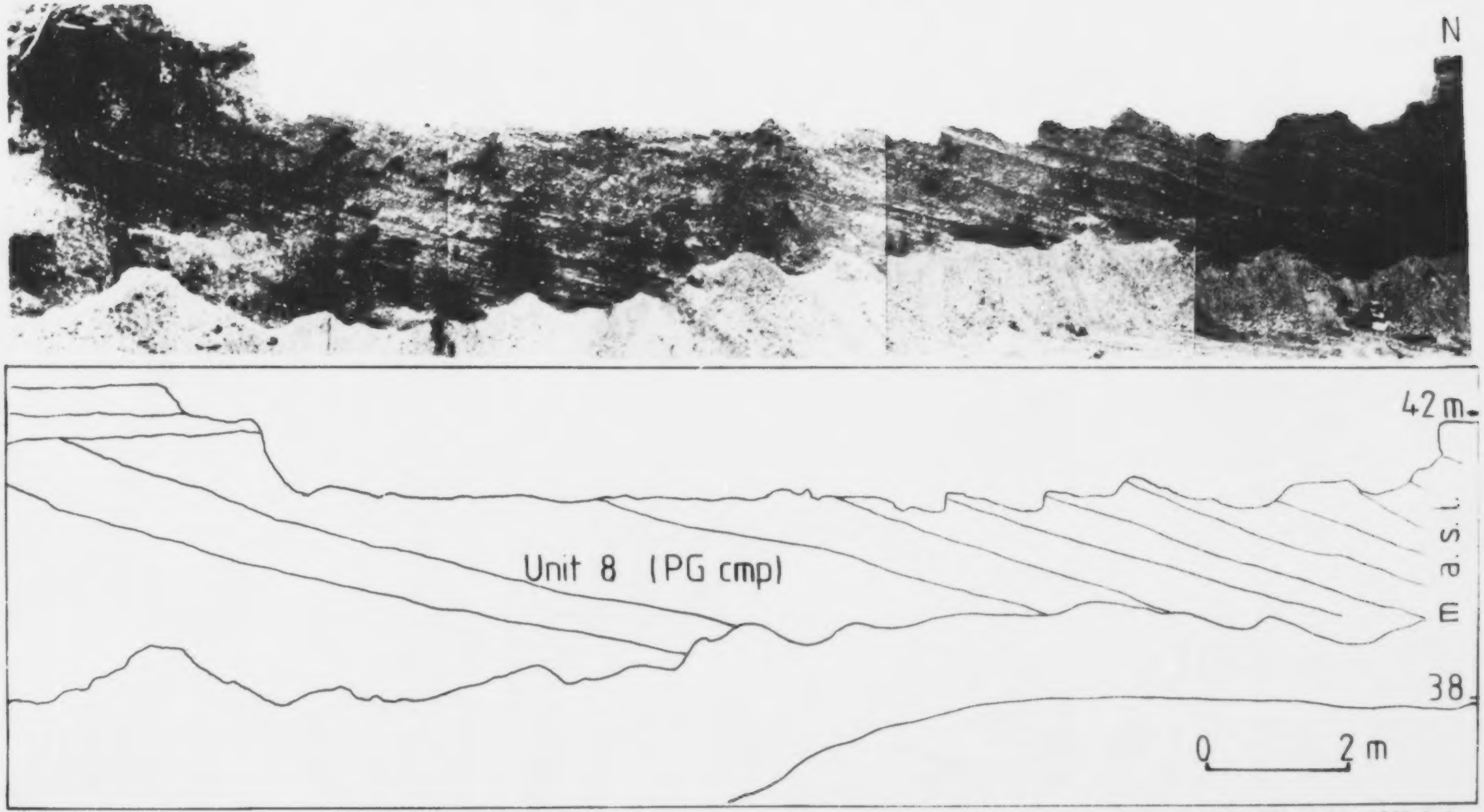


Figure 2.27. Photolog of Unit 8.

dated at 11 620 ± 250 yBP (BGS 1223). The shells were incorporated into an overturned, black, stratified, fine sand (Ss) layer which is overlain by a thin (0.30 - 0.50 m) reddish-brown diamict. The shells were predominantly adult, intact, and showed no signs of reworking. Samples of the sand were obtained for foraminifera and pollen analyses. Bryozoans were abundant in the sample and were observed encasing organic material (F.E. Cole, personal communication). Black organic fragments, believed to be eel grass (Zostera marina) were also observed in the sand. Foraminiferal analysis on a 20 cc sample by D.B. Scott (personal communication) indicated abundant planktonic species. Planktonics are generally more numerous than the benthonic foraminifera. The benthonic foraminifera were 12 specimens of E. excavatum f. clavata, 4 specimens of B. frigida, 2 specimens of Elphidium excavatum f. selseyensis, 1 specimen of Cibicides lobatulus, and 1 specimen of Discorbis sp. Bryozoans live within the photic zone; they, along with the planktonic foraminifera, indicate normal marine salinity and clear water. The presence of articulated, largely adult, populations of H. arctica indicates that the event that buried the shells was relatively sudden. The presence of eel grass would indicate shallow water. Pollen analysis showed the sample to be barren (Francine McCarthy and Robert Mott, personal communication).

UNIT 9

Unit 9 consists of iron stained, well sorted, horizontally stratified sand and gravel beds, which occur in ridges. The ridges are 1 - 2 m high and can be observed on aerial photographs (Figure 1.12) taken in 1935. The pebble to granule sized gravel is open work (Figure 2.28). The unit has limited exposure due to gravel extraction, but could be seen at the east end of the beach (Figure 2.14) and along the boundary between the C&E and GO pits. Where visible, the lower contact of this unit was unconformable.

Other dated material

Barnacle pads were found at Taylor's Island, anchored on freshly exhumed, glacially striated bedrock surface (Figure 2.29). They had been buried by sand and gravel. Barnacles recovered from the sediments adjacent to the bedrock, by A. Seaman (personal communication), were C-14 dated at 12 040 ± 150 yBP (BGS 1010). The barnacles were identified by K. Strand Petersen (personal communication, Danish Geological Survey) as B. crenatus at approximately 12 m a.s.l. (See B. crenatus description in Unit 1 (foreset gravel facies) for present-day depth range of these barnacles). P-forms

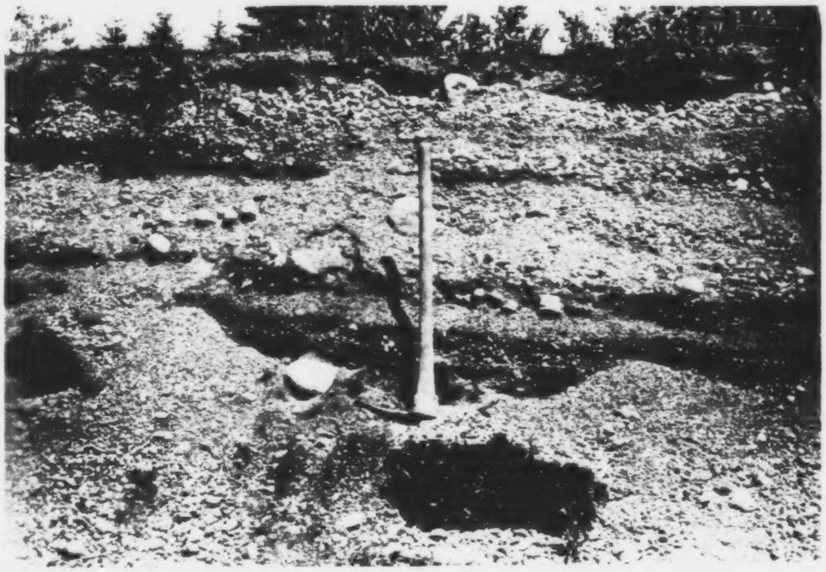


Figure 2.28. Photograph of the open-work gravel of Unit 9. (Figure 2.3 photograph location m)

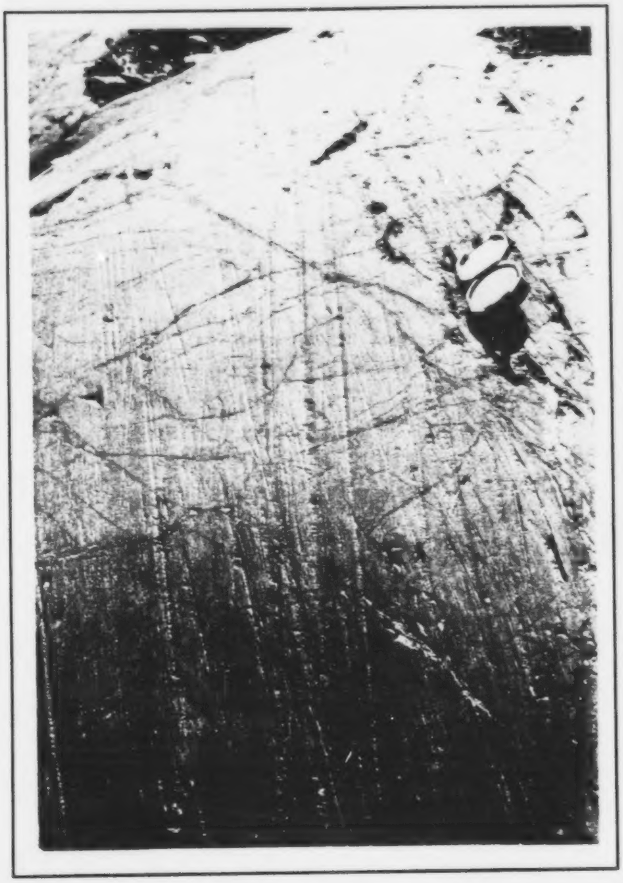


Figure 2.29. Photograph of the striated bedrock surface at Taylor's Island. The striations are southward.

were also observed on the above bedrock exposure.

A peat deposit is exposed on the head wall of a slumped block at the west end of the beach bluffs adjacent to Saints Rest Beach, in an area of large slumped blocks. The area is extensively covered with vegetation and slumped material and, therefore, cannot be mapped. The peat overlies a grey, pebble sized, matrix supported gravel. Unconformably overlying the peat is approximately 1 m of grey, sandy, stony, diamict with faint, reddish-brown stratifications. The diamict is overlain by a soil horizon approximately 0.7 m thick. The peat sample was C-14 dated and the pollen analysis completed by R. Mott (personal communication) (Figure 2.30). C-14 dates obtained on the peat were: 10 500 ± 200 yBP (BGS 916), 10 800 ± 120 yBP (GSC 4055) and 10 700 ± 120 yBP (GSC 4053). Mott (personal communication) interpreted the decrease in the total pollen percentage in the middle of the peat layer, to combined with the general increase in herbs in this layer indicate a climatic deterioration during the brief interval defined by the C-14 range.

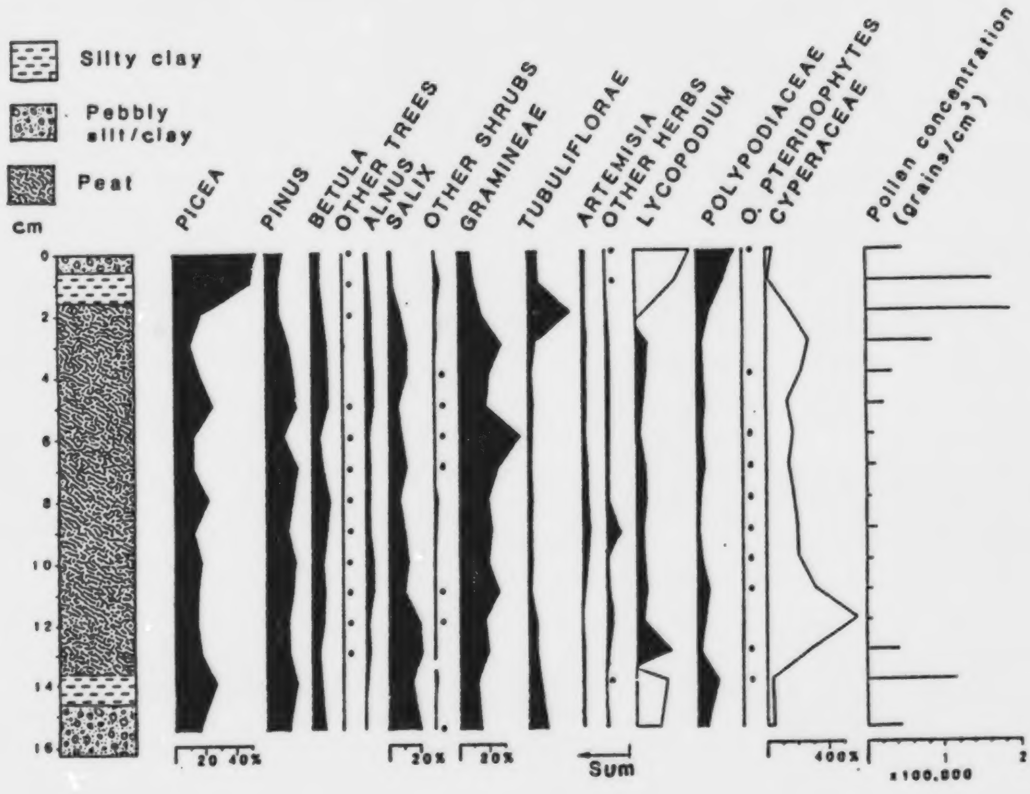


Figure 2.30. Pollen profile of the peat exposed at Sheldon Point. (R. Mott, personal communication).

CHAPTER 3

Interpretation

This chapter provides an interpretation of the facies and units outlined in Chapter 2. The predominance of gravel and sand and the presence of diamict, indicate that the Sheldon Point deposit is a product of subaqueous, ice-contact sedimentation.

UNIT 1

The presence of diamict, and its interfingering relationship with gravel deposits indicate proximity to the glacier. The inclusion of articulated *H. arctica* shells in the gravel and in the reddish-brown diamict, shows that the unit was deposited in a marine environment. The C-14 dates obtained from this unit varied: 13 900 ± 620 yBP (GSC 3354), 13 100 ± 160 yBP (GSC 3557) and 13 070 ± 370 yBP (GX 13824) (see Table 3.1).

The diamict facies

Two massive diamict facies, distinguishable by their grain size and colour, were observed within the

Table 3.1
Dated Material from Sheldon Point

Lab No.	Date	Error	Elevation	Material used for C-14 dating	*Reference
GSC 3354	13900	620	45	Ha	1
I(GSC)7	13325	500	3	*Ro,Pa,Pf	1,2,3,4
GSC 965	13200	200	6	Mc,Mt,Ha	1,2,3
GSC 3557	13100	160	45	Ha	1
GX 13824	13070	370	35	Ha	7
GSC 1340	13000	170	9	Mb,Mc,Pa,Ba,Mt,Sg,Ha	1,2,3
GX 12971	12650	175	25	Me-articulated	7
BGS 1010	12040	150	12	Barnacles	6
BGS 1223	11620	250	37	Ha	7
BGS 916	10500	200	10	bulk peat	6
GSC 4055	10800	120	10	upper 2 cm of peat	5
GSC 4053	10700	120	10	basal 2 cm of peat	5

deposit. The greyish-brown diamict was exposed at three locations. The fissility, small scale thrust faulting of underlying sediments, striated boulders and the stiffness of this diamict indicate a lodgement till (Dreimanis, 1976).

The greyish brown diamict

1) The greyish-brown diamict facies, located in the bluffs adjacent to Sheldon Point, is interpreted as the stratigraphically lowest and oldest exposure of this facies observed in the study area. This interpretation is based on 1) its proximity to bedrock 2) it is unconformably overlain by Unit 2, and 3) shell material is absent. The depositional environment of the diamict facies exposed at this site is interpreted as subglacial deposition by a warm-based tidewater glacier grounded at Sheldon Point.

2) The two exposures in the C&E pit are located at the crest of the ridge passing through Sheldon Point. The two exposures are at similar elevations and the diamict facies interfinger with similar facies (Figure 2.7). At the west end of this exposure small scale thrust faults were observed in the underlying sediments. The thrust faults suggest deposition by an overriding, southward flowing ice mass. It is unlikely that the deformations were formed by downslope movement as the folds are overturned upslope. The interfingering of the

gravel and diamict facies is interpreted as subglacial and subaqueous deposition adjacent to both the grounding line and a meltwater tunnel (Figure 3.1). Small advances and retreats of the glacier resulting from changes in the mass balance, created the interfingering relationship between the gravel and diamict. Changes in mass balance can be caused by seasonal variations, fluctuations in sea level, seasonal sea ice, or surging (Boulton, 1986; Solheim & Pfirman, 1985).

3) At the third location, the diamict was poorly exposed, but is interpreted as subglacial deposition (Figure 3.2).

The reddish-brown diamict

This diamict is till-like, generally thin, non-compact and resembles a meltout till (Dreimanis, 1976). No distortions of beds below this facies were observed. The interfingering relationship of beds of diamict and gravel suggest proximity to the grounding line. Therefore, the reddish-brown diamict is interpreted as either a basal meltout till, ablation meltout till or flow till (based on Dreimanis, 1976) or, more generally, a waterlain till (Dreimanis, 1982). The interpretation for this diamict facies is deposition in subaqueous ice proximal conditions following a brief retreat (Figure 3.2). The deposition occurred along the grounding line where a narrow ice shelf extended for a few tens or

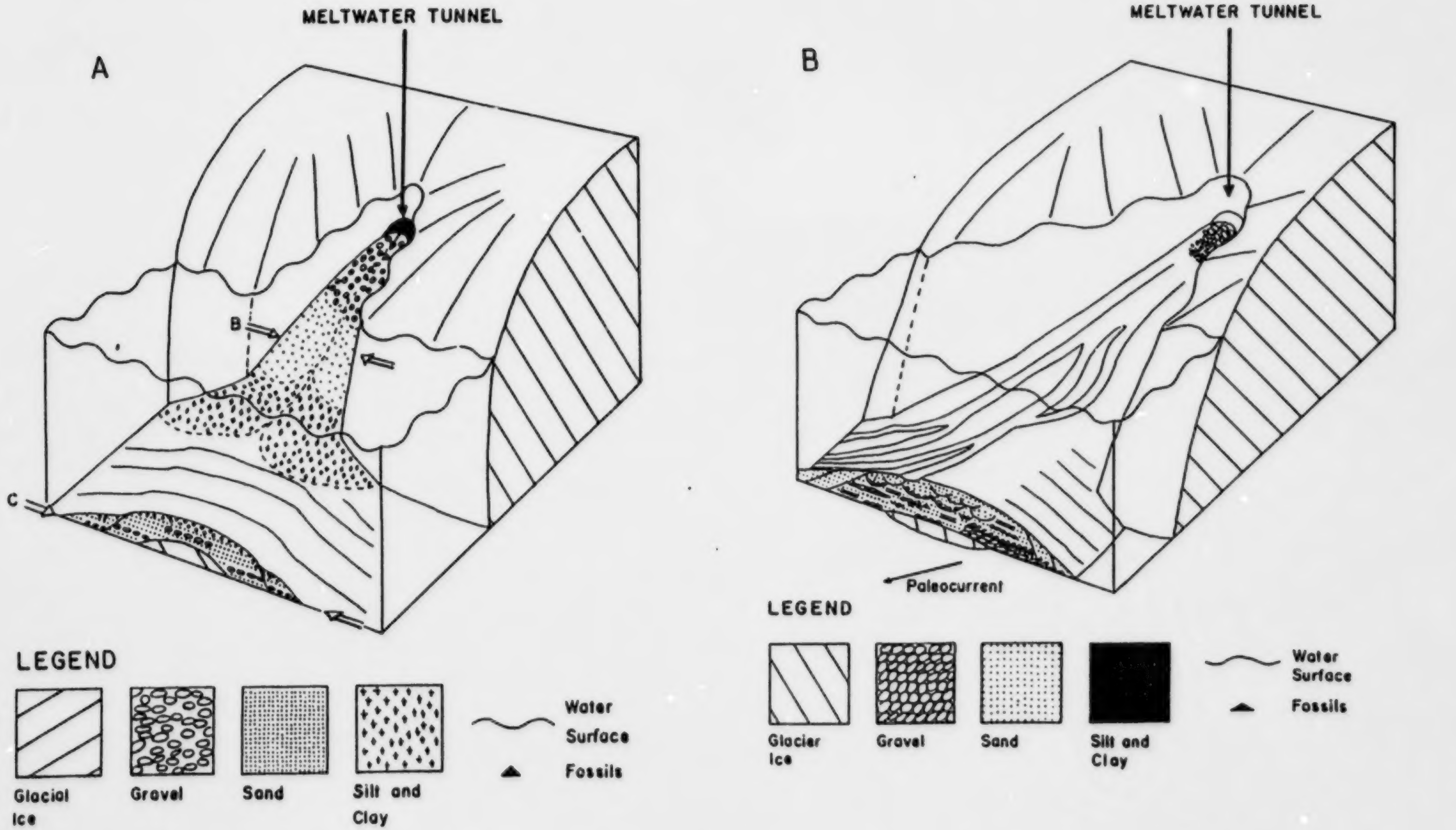


Figure 3.1. Figure from Cheel and Rust (1980) illustrating the depositional environment of the gravel facies of Unit 1 and the sand facies of Unit 2. a) illustrates how the buried ice can be incorporated into the deposit . b) illustrates the effect of currents on deposition.

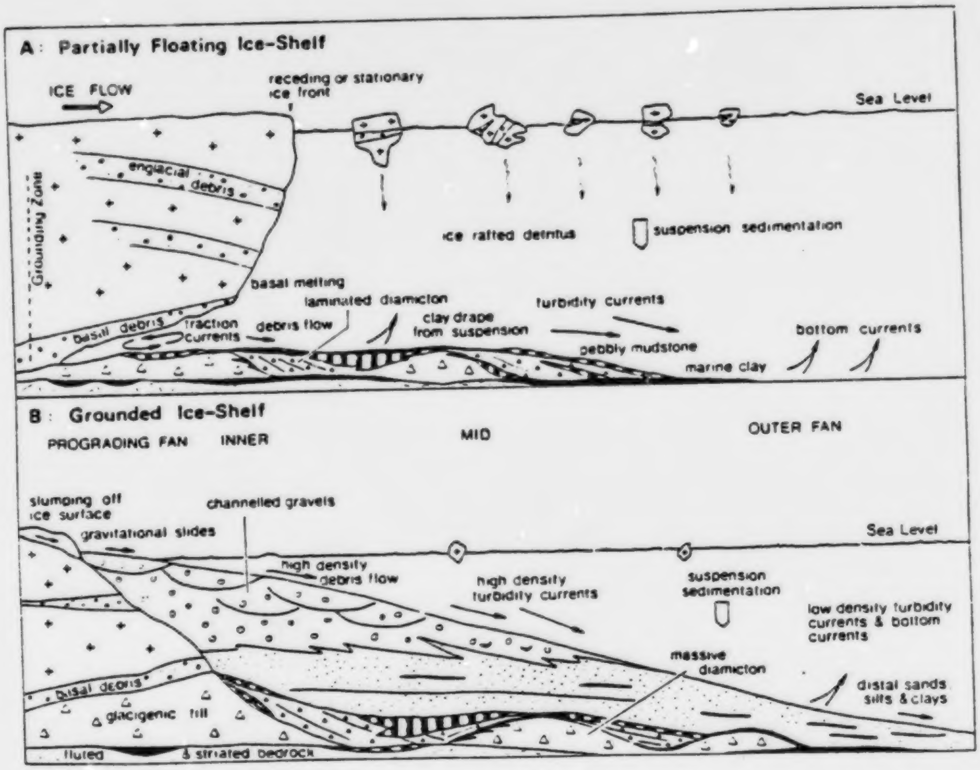


Figure 3.2. Figure from McCabe et al., (1984) illustrating a cross-sectional view of the composite model of depositional environments adjacent to a grounded tidewater glacier.

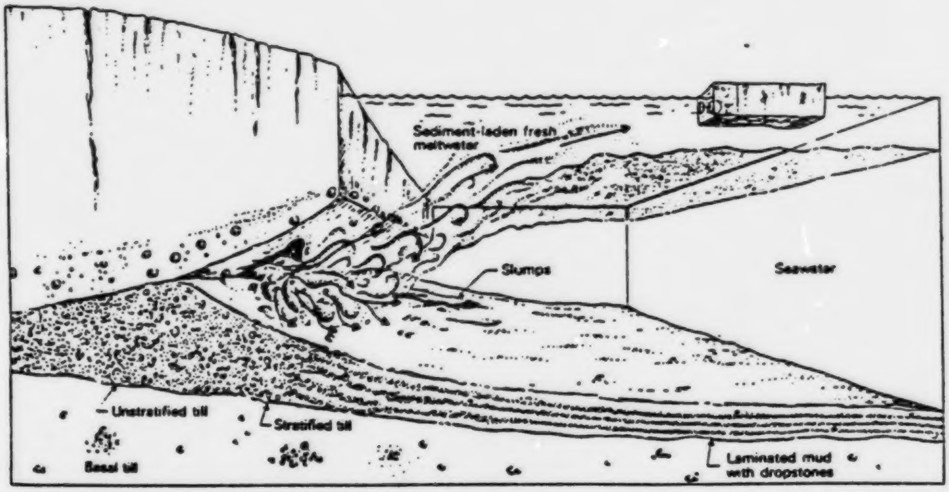


Figure 3.3. Figure from Miall, (1982) illustrating glaciomarine deposition and the formation of a stratified diamict (=stratified till).

hundreds of metres (Figure 3.3). The water depth beneath the floating glacier ice was only a few metres. Deposition may have been from basal, englacial, or supraglacial material. The difference in the colour and texture of this diamict facies from the lower diamict facies either indicates incorporation of fine grained, seabed material, or a change in source material. Two similar colours of till have been noted by Gadd (1973) in southern New Brunswick. Gadd (1973) (p.7) found that the grey coloured tills dominated the western and southwestern areas underlain by slates, schists, and argillites. The reddish brown shades are common in the central and northeastern parts of southern New Brunswick in areas underlain by predominantly dark red sedimentary rocks.

The most likely reason for the change in colour of the diamicts at Sheldon Point is a change in source material. The coarser greyish-brown diamict contains rounded boulders of pink granite. This bedrock is common in the St. Croix Highlands northwest of Saint John. The reddish-brown colour of the finer grained diamict is due to the incorporation of the maroon conglomerate of the Kennebecasis Formation to the north of Saint John. The change in colour represents a change of the dominating ice centre. Initially, the North

Maine ice divide, which was located northwest of Saint John, controlled deposition at Saint John (Rampton et al., 1984). Subsequently, the Gaspereau ice centre, to the north, became the controlling ice centre for deposition in Saint John and southern New Brunswick (Rampton et al., 1984).

The normally graded gravel facies

Similar graded gravel facies have been identified by Eyles et al. (1987) and Bannerjee and M^{c}Donald (1975) in ice-contact, subaqueous, lacustrine deposits. These sediments have been transported by downslope mass flow, perhaps generated by a subaqueous slump a short distance upslope.

Faults in glaciofluvial sediments are interpreted by M^{c}Donald and Shilts (1975) as internal displacements in the sedimentary sequence resulting from either: 1) the melting of buried glacial ice; or 2) melting of ice walls supporting the sediment (eg. within an esker). Normal faults record extension, during slumping, of an ice free face to produce an equilibrium slope (M^{c}Donald and Shilts, 1975, p. 123). The presence of these faults provides proof that the unit is associated with ice-proximal glaciofluvial sedimentation. The faults parallel the ridge at Sheldon Point and are located on the northern flank of the ridge. Figure 3.4, (from Gustavson and Boothroyd, 1980, p. 106) illustrates how buried glacial ice can be incorporated in a deposit.

Trough cross-bedded sand to gravel facies:

The association of this facies with facies interpreted as mass flow deposits (normally graded gravel facies above) was noted by Eyles et al., (1987 p.208) who attributed its formation to:

> " decreasing flow velocities and sediment concentration at the end of turbulent flow when traction structures such as dunes begin to develop."

The massive sandy gravel facies

This facies is typical of coarse grained, poorly sorted, subaqueous, outwash sediments dumped at the margins of glaciers (Eyles et al., 1987; Rust and Romanelli, 1975) and subaqueous, mass flow deposits (Nemec and Steel, 1984).

The foreset gravel facies

The foreset gravel facies, because of the repeating fining upward sequences, is interpreted as the product of gravity winnowing processes (Postma, 1984) adjacent

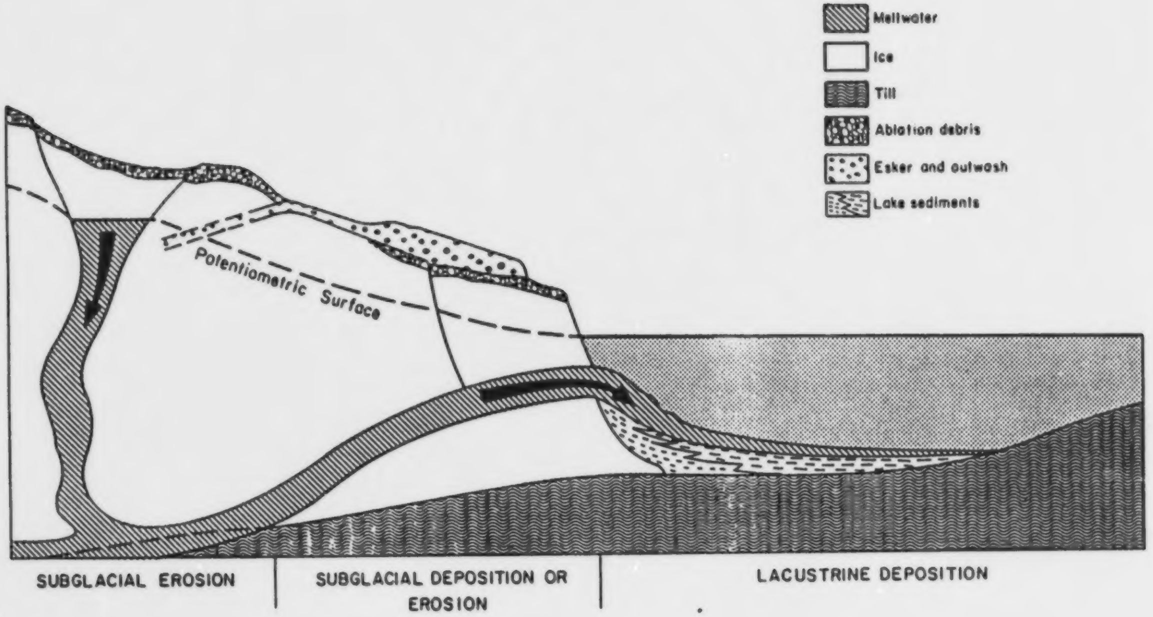


Figure 3.4. Figure from Gustavson and Boothroyd, (1980) illustrating a hypothetical model of subaqueous supraglacial deposition and the burial of glacial ice.

to an unstable sediment mass (Figure 3.5). The slope is destabilized due to the retreat of the ice.

Cluster bedforms form in response to varying flow velocity around an isolated clast on a streambed. Clusters are generated following bedload movement (Brayshaw, 1984). Cluster bedforms have been reported by Brayshaw (1984) from a fluvial environment and by M^{c}Cabe et al. (1984) from a proximal glaciomarine environment. They were probably generated during the waning stages of a debris flow.

The stratified diamict facies

Stratified diamict is glaciogenic material modified by deposition in water, and has been described by many authors (Gibbard, 1980; Dreimanis, 1982; M^{c}Cabe et al., 1984, Eyles et al., 1985). Stratified diamicts are transitional sediments occurring between glacial and glaciomarine sedimentation. They represent sedimentation in a marine environment proximal to the grounding line (Figure 3.2). The fact that the stratified diamict is sometimes interbedded with gravel suggests proximity to a meltwater source.

The change in colour within this facies is due to a change in source material as described in the massive diamict facies.

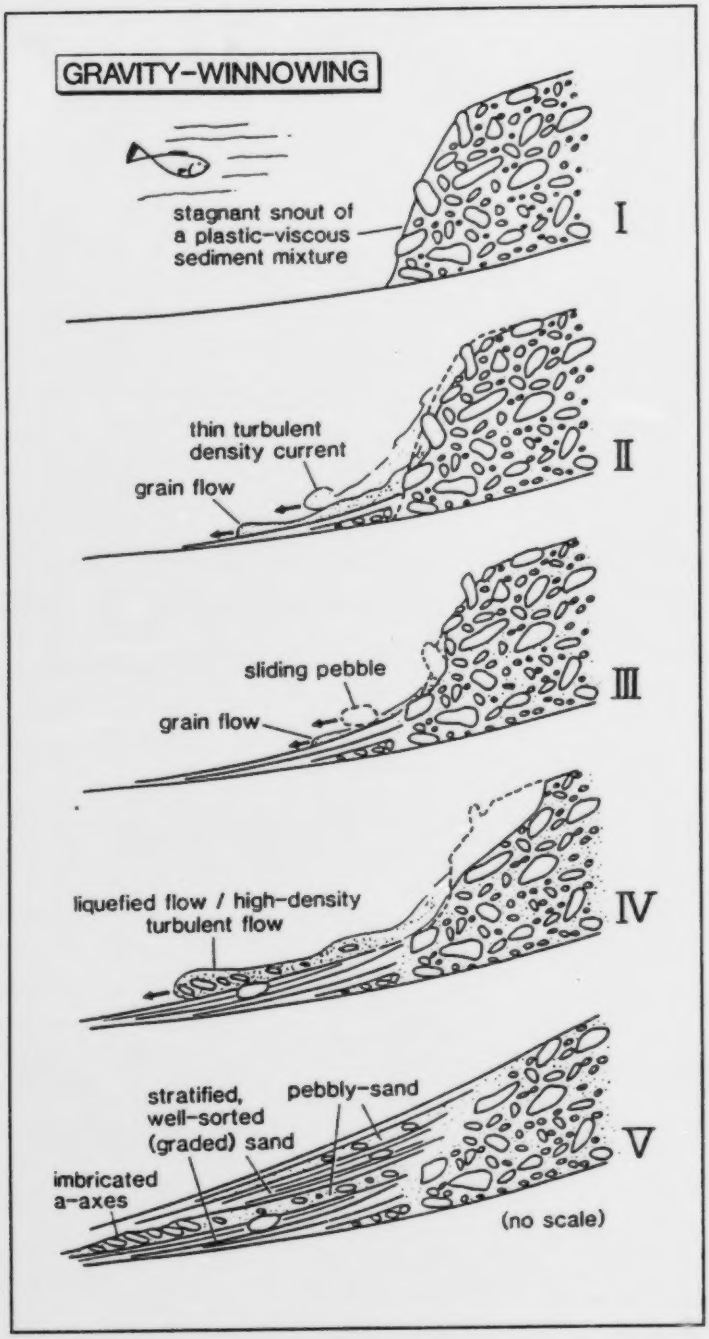

GRAVITY-WINNOWING
stagnant snout of a plastic-viscous sediment mixture
I
thin turbulent density current
grain flow
II
sliding pebble
grain flow
III
liquefied flow / high-density turbulent flow
IV
stratified, well-sorted (graded) sand
pebbly-sand
imbricated a-axes
V
(no scale)

Figure 3.5. Figure from Postma, (1984) (p.255) illustrating the gravity winnowing process from the snout of a stationary, but unstable, plastic-viscous sediment mass.

The sand facies

The graded sand facies is composed of stacks of coarse, graded sand. Eyles et al. (1987) report a similar facies and interpret it as rapid deposition from turbulent suspension at the base of a turbidity current. Faulting within the sand indicates the presence of buried glacial ice.

Summary of Unit 1

The overall thickness of Unit 1, in the C&E pit, is between 20-30 m. The central part of the deposit (C&E pit) is primarily gravel, with diamict and stratified diamict beds, indicating that the major component of deposition is from a glaciofluvial source. At the time of the deposition of this unit, glacial ice was grounded below sea level (sea level > 45 m above the present level). The gravel facies (BGmm-PGmm, PGmg, PGp) of Unit 1, bedforms such as cluster bedforms, and imbrication, indicate high current regimes and mass flow deposition. The thickness of the unit, bedforms, and facies relationships suggest a junction between a high energy glaciofluvial and low energy marine environment. At this point, the sudden loss of energy deposits a large amount of sediment. The environment during the deposition of Unit 1 is interpreted to be very cold (macrofossil assemblage) and turbid with abundant input of meltwater. The interfingering of the diamict and gravel, the high flow regime, the wide variability in flow directions, and the lack of lower current regimes, indicate that the meltwater conduits quickly opened and closed along the ice margin. Subglacial-stream discharge changes on a seasonal basis (Powell, 1981 p.132).

The limited macrofossil species (see Unit 1 description in Chapter 2) within this unit may be attributed either to the nature of the depositional environment or to the lag time between deglaciation and the migration of species into the area (M^{c}Cabe et al., 1984).

UNIT 2

The two facies of Unit 2 are a normally graded sand and a stratified sand facies containing cobbles and boulders. Unit 2 is only found on the distal slope of the ridge, where it dips south. These facies do not interfinger with other facies and unconformably overlie the massive greyish-brown diamict. The graded sand facies of Unit 2 differs from the graded sand facies of Unit 1 in that the individual beds fine and thin upwards in Unit 2. Unit 2 is interpreted as a proglacial deposit, formed while the ice was grounded at Sheldon Point (similar to the sand facies illustrated in Figure 3.1).

The normally graded sand facies

This facies is interpreted as either: 1) a proglacial mass flow (or sediment gravity flow) deposit (similar to the type IIB facies, Postma et al., 1983) or 2) a deposit formed from underflows generated from subglacial meltwater discharge as described by Powell (1981). The graded sand is interpreted as proximal glaciomarine and time equivalent to the diamict/gravel interfingering in the C&E pit (Site 2 diamict facies). The presence of stacked, fining and thinning upward packages of graded sand suggests a succession of turbidity flows (Eyles et al. 1987), mass flows, or underflows. Prior et al. (1981), found that submarine slopes of fjord head deltas are subject to instability. Sediment instability is common in the marine environment because of increased pore pressures, gas-charged sediments, and high sediment accumulation rates (Bouma et al., 1981). Prior et al. (1981), suggested that delta front instability is expressed as multiple, small scale events that recur at frequent intervals. The fining and thinning is attributed to pulsations in the flow which cause a decrease in flow velocity (Eyles et al., 1987).

The sharp change in colour within this facies is believed to correlate with the change in colour observed in the diamict facies.

The stratified sand facies

The stratified sand facies contains boulders, is coarser at the base, and fines upwards. This facies is interpreted as a distal equivalent of the graded sand facies discussed above. The incorporation of large cobbles and boulders is interpreted as deposition by icebergs or sea ice. No iceberg scours were observed. The topographically high Sheldon Point deposit trapped icebergs, produced by the glacier, when the glacier was grounded on the northern slope. Only the smaller icebergs drifted over the deposit, accounting for the absence of iceberg scours. In addition, the primary form of ablation of mid-latitude, tidewater glaciers is by meltwater and brash ice rather than icebergs (Powell, 1983; Molnia, 1983; Anderson et al., 1983).

Summary of Unit 2

The overall fining upward nature of the unit indicates either increasing sea level, or an increase in distance from the sediment source. The increase in distance from the source could be created by the following: 1) retreat of the ice, or 2) retrogressive flow slides (Postma, 1981) or 3) both 1 and 2. Flow slides are retrogressive because the slide scar replaces itself further upslope (Postma, 1981).

The unit represents proximal to distal, proglacial, glaciomarine deposition adjacent to a subaqueous outwash deposit. No shell material was observed in this unit. The change in colour within the graded sand facies, the lack of interfingering with other facies, the unconformity between the lower diamict and Unit 2, and the absence of normal faulting indicate that this unit was syndepositional with Unit 1.

UNIT 3

Unit 3 is characterized by broad, U-shaped troughs filled with matrix supported gravel. The upward thinning and fining, and the repetition of sequences within the troughs, is indicative of mass flow deposition. Upward decrease in the size of the troughs, and the upward fining of the trough fill indicates waning flow conditions. The shape and fill of this unit resembles the proximal mass flow deposit of the Drente Formation. This was observed in the Leuvenumsche Beek

Valley described by Postma et al., (1983). The troughs were scoured by mass flows which act like a "rigid" sediment plug (Postma et al., 1983). The mass flows were localized between trough-shaped boundaries formed by the slump scar itself (Postma et al., 1983).

Most documentation suggests that mass flow deposition, in an ice-proximal environment, is on the proglacial side of the deposit. At Sheldon Point, mass flow deposits were observed on both sides of the feature. The flows on the ice-contact face, Unit 3, were formed due to the retreat of the ice margin or from the meltout of buried glacial ice. Unit 3, therefore, is interpreted as reworking of the over-steepened, ice-proximal side of the deposit by sediment gravity flows, following the retreat of the glacial ice.

Unit 3 is older or contemporaneous with Unit 4, and younger than Units 1 and 2.

UNIT 4

Unit 4 was observed on the north and south face of the ridge. Unit 4 is a rhythmic sequence composed of silt, sand, clay, and muddy gravel that resembles the Emerald Silt described by King and Fader (1986), and the Presumpscot Formation described by Bloom (1963). The base of the sequence resembles Facies A Emerald Silt

(King and Fader, 1986). Higher in the section, Unit 4 fines and resembles Facies B Emerald Silt (King and Fader, 1986). Facies A Emerald Silt has been interpreted by King and Fader (1986) to represent deposition by rain out below an extensive, floating, ice shelf. Facies B represents the transition from a floating ice shelf to open water conditions and the deposition from drift ice (King and Fader, 1986).

Unit 4 could not have been formed below an extensive floating ice shelf because of the shallow water depth (< 100 m) (Domack, 1983; Eyles et al., 1985). The highest sea level estimated for the Saint John region is 70-80 m (Rampton et al., 1984) and the deposit itself is up to 40 m a.s.l. Similar rhythmic sequences have been described and interpreted by Cohen (1983) and Eyles et al. (1987) as the fine grained rhythmites in a delta foreset, in a similar, but glacial-lacustrine environment. Eyles et al. (1987) explain their formation (p. 210):

> " such sequences are common on the lower parts of glaciolacustrine delta fronts and are products of turbid underflows associated with meltstreams."

Underflows are less common in a marine environment because of the greater density of sea water. Powell (1981), however, explains that underflows can be formed in a glaciomarine environment if large quantities of fine grained material are available for fluvial transport. In addition, the large input of fresh water from meltwater sources may reduce the density enough to allow the formation of underflows in a shallow, glaciomarine environment. A portion of the sediment is present because of the "raining out" of debris from interflows and overflows in the quiet waters beneath sea ice.

The association of the muddy gravel layers with the large troughs of Unit 3 suggests input from mass flow deposition. Mass flow deposition from the north face of the Sheldon Point deposit and mass flow deposition from the south face of the Manawogonish moraine would have contributed sediment to this unit. Sea ice was probably present most of the year because of increased meltwater, due to the ablation of the glacier (Boulton, 1986). The sea ice would have sheltered the area from reworking (Honig and Scott, 1987).

At Sheldon Point, the presence of the sandier sequence at the top of the unit represents the exposure to shallow water marine conditions at the Manawogonish moraine because of falling sea level and the lateral encroachment of the ice-contact fan. The sequence may represent more open marine conditions due to a reduction in the time of sea ice cover. Eyles et al. (1987, p.209) attribute the formation of a similar sequence in a glacial-lacustrine environment to deposition by turbidity currents under conditions of decreasing flow velocities.

Unit 4 is interpreted as a glaciomarine sequence. At the time of its formation, glacial ice was grounded nearby, but not at Sheldon Point. There was no extensive ice shelf due to the shallow water depth (less than 70 m)(Domack, 1983). This unit is interpreted to have formed while glacial ice was grounded at Manawogonish moraine. The sharp ice contact northern face of the Manawogonish moraine and the beach ridges, observed on air photographs (Figures 1.11 and 1.12), indicate that sea level was lower than the Manawogonish moraine while the ice was grounded at this location. It can be inferred, therefore, that sea level stood at less than 65 m a.s.l. during the deposition of this unit. This interval represents a period of time younger than 13 100 yBP (GSC 3557, and GX 13824 from Unit 1) and older than 12 650 ± 175 yBP (GX 12971 from Unit 6).

UNIT 5

Unit 5 is composed of a massive, reddish-brown mud. Mud is the dominant sediment type in distal areas adjacent to a land based glacier (Powell, 1981). When the glacier retreats from the sea, the coarse component (sand and gravel) becomes trapped in sandur deposits and on the top of outwash deltas (Powell, 1981). As the ice retreats, lakes are often formed between land based moraines and the glacier, trapping large amounts of sediment. Very little ice rafted debris is found in the distal mud because the glacier was not calving into the sea.

Unit 5 is interpreted as marine deposition (rather than glaciomarine), adjacent to a land based glacier. The glacier probably retreated to the South Bay moraine location. The southerly Manawogonish moraine blocked the transport of icebergs, and restricted meltwater and sediment from reaching Sheldon Point. The South Bay moraine, at this time, may not have been exposed to the sea. There is no evidence of marine reworking at the South Bay moraine.

Small scale thrust faults, within this unit, indicate glacial tectonic deformation originating from the northwest. There are also large scale normal faults observed within this unit. The presence of these faults could be a result of glacial encroachment or down slope movement. Articulated shells that appeared in situ were fractured. F.E. Cole (personal communication) suggested that fracturing of the shells could have occurred because of the pressure exerted by an overriding ice mass. No diamict was observed, however, in association with this unit.

UNIT 6

The repeating, fining-upward (gravel to sand) sequences within this unit suggest mass flow deposition. Unit 6 resembles the mid-to-distal portion of the Drente Formation in the Leuvenumsche Beek Valley (Postma et al., 1983). The Drente formation was interpreted by Postma et al. (1983) as originating from sediment gravity flows in an ice-marginal lake associated with ice-pushed ridges. Large-scale normal faults observed in this facies are interpreted as forming from the melting of buried glacial ice. These faults were not observed in Unit 7 above. The presence of these faults, and the thrust features in the unit below, indicate encroachment of glacial ice from the northwest. Cluster bedforms and imbrication within the sediments indicate that Unit 6 formed by mass flow deposition toward the northwest. The source of the sediments may have been the crest of the Sheldon Point deposit. Good preservation of a shallow-water mussel indicates rapid burial of a living community (F.E. Cole, personal communication). The shells may have been subject to subsequent matrix supported, mass flow deposition.

It can be inferred that sea level was greater than 40 m a.s.l. (the height of the Sheldon Point deposit) and less than 60 m a.s.l. (the height of the Manawogonish moraine) for the time period indicated by the dated shells. *M. edulis* is normally an intertidal species but can be found in up to 30 m of water. It is possible, because the shells were found between 20 and 25 m a.s.l., that the shells were transported downslope.

UNIT 7

It is difficult to determine the age of this unit as the date from Unit 6 is 12 650 ± 175 yBP (GX 12971) and the date from the base of Unit 8 is 11 620 ± 250 yBP (BGS 1223). The only other date associated with this time interval was obtained from barnacles on Taylor's Island (See other dated material, Chapter 2). The event that buried the bedrock at this location is interpreted to be associated with Unit 8.

Unit 7 is interpreted to be associated with Unit 5 because of the transitional boundary between the two units. Unit 7 appears to infill small depressions in the topography. The wide range in flow directions, together with the faults observed in Unit 6 and the small scale thrust features observed in Unit 5, indicates that Units 6 and 7 are associated with a re-advance of the glacier. There is no diamict associated with Units 5, 6, and 7. The glacial ice, therefore, may not have overridden the Sheldon Point deposit. It is, therefore, interpreted that glacial ice encroached from the northwest, and supplied limited glaciofluvial sediments to the Sheldon Point area. It appears that the ice re-advanced after Unit 5 was deposited, but was proximal and probably responsible for the deposition of Unit 6.

UNIT 8

At the base of the unit, a thin reddish-brown diamict unconformably overlies an overturned fine sand layer. The shape and direction of foresets indicate glaciofluvial deposition from a source south of Sheldon Point. Presently, the Sheldon Point deposit is the most southerly feature in the area. Ice may, therefore, have re-advanced filling the harbour south of Sheldon Point.

The direction of re-advance is speculative. There is some indication (meltwater flow direction) in northeast Saint John of a southwestward flow (Figure 3.6). In addition, Robert Melvin (personal communication) stated that he had observed a diamict overlying glaciomarine sediments in east Saint John.

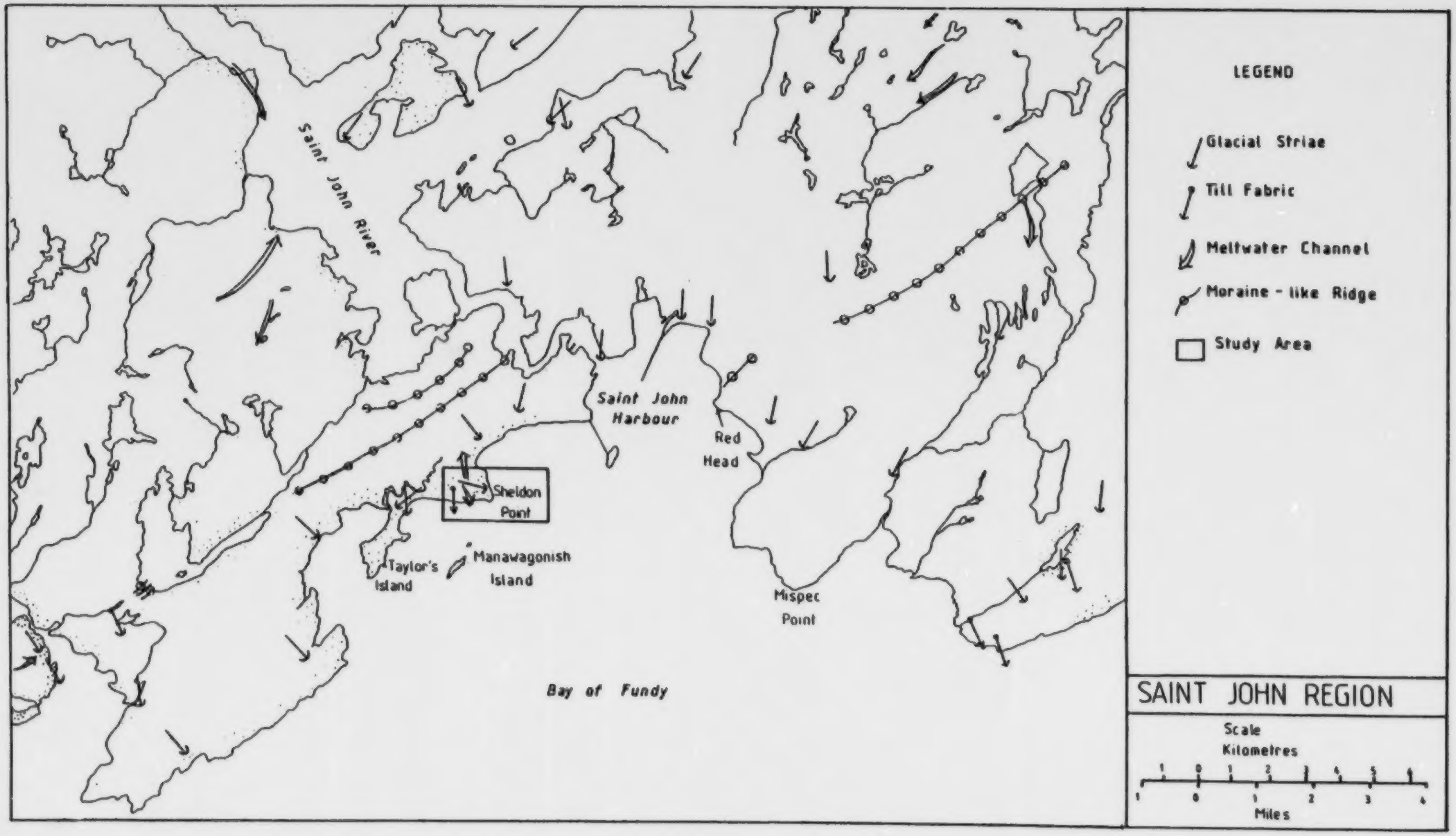


Figure 3.6. Figure illustrating glacial striations, the results of till fabric analyses, meltwater channels and moraine-like features in the Saint John Region. Map compiled from A. Ruitenberg (personal communication), Rampton et al., (1984), and Gadd, (1973).

There was no indication, however, of the age of the overlying diamict. Melvin (1966) identified a buried river valley in east Saint John and proposed a pre-late Wisconsinan outlet for the Hammond River. Glacial ice appears to have retreated east-northeastward, along the strike of the river valley (Melvin, 1966). It is possible, therefore, that local late-glacial ice could have readvanced down the Hammond River, filled Saint John Harbour, and provided a glaciofluvial source for Unit 8.

The large foresets of Unit 8 are "classic" foresets composed of coarse clastic materials. Occasionally the top of the bed displayed an epsilon shape and may indicate that sea level stood at approximately 45 m during their deposition. Honig and Scott (1987) projected that sea level stood at 45 m, earlier, at approximately 14 000 yBP in the Passamaquoddy Bay area. Scott (personal communication) suggested that the difference in age in the sea level stands may be attributed to depression due to the presence of late glacial ice in the Saint John region. This unit dates a re-advance of the glacier, to this location, between 11 620 ± 250 yBP, the date obtained from the shell material at the base of Unit 8, and 10 800 ± 120 yBP, the oldest date obtained from the peat. Microfossils (planktonic and benthonic foraminifera and bryozoans) obtained from the base of this unit indicate that normal, shallow marine conditions prevailed at the onset of the deposition of this unit. Pollen data from the same sample indicate glacial cover. A land based glacier, therefore, was present at this time. The presence of these large foresets is the best indication of proximal, late-glacial ice in the Saint John Harbour region.

UNIT 9

Sea level was probably between 40 and 45 m above present sea level during the initial deposition of this unit. The large, planar-tabular foresets of Unit 8 were truncated by Unit 9 between 40-43 metres. In addition, the Sheldon Point deposit has a planed-off surface between 40 and 45 m. Unit 9 resembles a beach deposit. Beach ridges and benches can be observed on air photographs (Figure 1.11 and 1.12) and probably record falling sea level. As shells were not found in these units it is impossible to determine the rate of sea level fall for the Sheldon Point area. The limited reworking of the deposit suggests rapid fall of sea level.

Summary

At least half of the Sheldon Point deposit is below present sea level. The portion observed above sea level, the only portion accessible for study, represents the late stages of ice-contact deposition and deglaciation at Sheldon Point. Glacial ice was grounded here for some time prior to the oldest reliable shell date. Glacial ice, therefore, was grounded at Sheldon Point prior to 13 500 yBP. The ice margin was fluctuating at Sheldon Point at approximately 13 500 to 13 000 yBP. Between 13 000 and 12 800 yBP, ice retreated to the Manawogonish moraine and sea level fell below the height of the Manawogonish moraine. By 12 600 yBP, glacial ice had retreated to the South Bay moraine. Glacial ice re-advanced and encroached upon the Sheldon Point area between 12 800 and 12 500 yBP. There is limited evidence that glacial ice overrode the Sheldon Point deposit at this time.

There appears to be an interval of non-deposition between 12 500 and 11 700 yBP. During this period, barnacles lived on the bedrock at Taylor's Island. The biota indicate normal, shallow marine conditions. By the close of this interval, glacial ice had re-advanced.

The ice re-advanced to the Sheldon Point area after 11 620 ± 250 yBP, deposited the foreset facies and buried the barnacles at Taylor's Island. Glacial striations were observed on the freshly exhumed bedrock surface at Taylor's Island. These are interpreted to have originated from earlier glacial erosion because of the preservation of barnacle pads (Figure 2.25). During the glacier re-advance, sea level was between 40 and 45 m. Falling sea level and climatic cooling (Mott, 1986) caused the re-advance of a local glacier centre. Ice had retreated from the Sheldon Point area and sea level had fallen from 40 m to 10 m by the time peat was deposited. This ice re-advance to the Sheldon Point area probably occurred during a short time interval between 11 500 and 11 300 yBP. This would provide a time interval of 500 years for sea level to fall from 40 m to 10 m. Similar rates of sea level fall have been suggested by Belknap et al. (in press) for the Maine coast during this time interval. The beach ridges of Unit 9 were formed during this interval. This represents the close of marine deposition at Sheldon Point.

CHAPTER 4

Discussion

The Sheldon Point deposit is a composite feature, recording glacial, glaciomarine, and marine conditions in the Saint John area for a time period of approximately 4000 years. The time interval of 14 000 to 10 000 yBP is a critical period in the deglaciation of southern New Brunswick and results of this study may have implications for the Saint John area and southern New Brunswick. In addition, this study provides information on glaciomarine sedimentation relevant to Canadian East Coast offshore areas. The purpose of the thesis was to determine the sedimentary conditions that formed the Sheldon Point deposit. The discussion will focus on the implications of the stratigraphy of the Sheldon Point deposit and the regional patterns of deglaciation in southern New Brunswick and Maine, and the implications of the study for glaciomarine sedimentation.

The Sheldon Point deposit is a transverse ridge delineating a former ice front position. This ridge was initially deposited while the grounded ice front was located below sea level (tidewater glacier). Sedimentation was probably dominated by rapid subaqueous fan deposition and mass flow deposition. It is suggested here that the Sheldon Point deposit is a glaciomarine end moraine.

Glaciomarine end moraines differ from classic subaerial end moraines in that glaciomarine deposition continues after the ice retreats. In addition, high pore water pressures and the fine grained nature of the marine sediments probably reduce the drag at the base of an advancing or retreating glacier. These factors contribute to the high activity of tidewater glaciers (Boulton, 1986). If a glacier remains grounded at one location for any length of time, a ridge forms. Once a continuous ridge forms, it acts as a dam for subsequent re-advances of the ice and, therefore, is the nucleus for compound glacial deposition (Boulton, 1986). At Sheldon Point, initially a subaqueous ice contact fan may have developed providing a nucleus for moraine formation. The ridge at Sheldon Point is probably an ice push moraine, formed along a "surging" margin of the glacier adjacent to a meltwater conduit. The surging may have been produced by climatic variations and/or seasonal sea ice formation. The Sheldon Point end moraine is a composite glaciomarine end moraine probably representing 3 phases of end moraine deposition. The morphology of the moraine, however, only reflects the first ice marginal position. The frontal moraine morphology was not appreciably altered by the subsequent re-advances. The preservation of the initial morphology reflects two factors influencing deposition: 1) the re-advances were very short in duration, possibly representing a surge and 2) the glacier re-advanced over fine grained materials which may have altered the profile of the glacier (Boulton, 1979). The gravel ridge at Sheldon Point would have altered and possibly halted the glacier flow.

Subaqueous end moraines in west Saint John and southern New Brunswick consist of several relatively short, closely spaced moraines within large areas having no other end moraines. In the Saint John region, end moraines are associated with paleo-river valleys. Three end moraines occupy the paleovalley of the Saint John River in West Saint John. The association of the three moraines confined within the bedrock paleovalley suggests that the Saint John River valley was occupied by a subglacial meltwater conduit. It is suggested that the Sheldon Point deposit is a "type" glaciomarine end moraine for the Saint John area and that the Manawogonish and South Bay moraines are similar in morphology. Furthermore, it is proposed that the Sheldon Point moraine may be used as a model of the east coast area for deposition by a glacier grounded in shallow water (<100 m) (marine or fresh), adjacent to a meltwater conduit.

Boulton (1986) found that widespread push moraine formation is favoured in locations where the glacier is stabilized long enough for a fan to develop. Ice contact fans form repetitively as the glacier front changes its position (Boulton, 1986 p. 696). These fans provide a nucleus for the development of push moraines. The association of thick sedimentary sequences in the Little River paleovalley and the Saint John River paleovalley (Figure 1.5) and the presence of subaqueous fan deposits at Sheldon Point indicate that the paleo-river valleys may have acted as a conduit for subglacial meltwater. Large ice marginal fans developed as the ice retreated at Sheldon Point, Manawogonish Moraine, and the South Bay moraine, creating large push moraines. Boulton (1986) found that large, well-spaced push moraines develop in areas where the ice velocity and calving rates are high. The mean position of the tidewater glacier front may have been constant for several years, however, it would have undergone seasonal and longer term variations (surge intervals range between 30 and 100 years) while it was grounded at the individual sites. The size of the ridges is a function of the availability and character of the sediment, the depth of the water body, and the amount of reworking by falling sea level (Boulton, 1986).

At Sheldon Point, ice push moraine formation is evident in the interfingering of the diamict and gravel facies of Unit 1. In addition, the coarsest grained materials are concentrated at the point of ice contact (the ridge at Sheldon Point), with a rapid distal reduction in grain size (Units 2 and 4) (Boulton, 1986). Figure 4.1, from Boulton (1986), illustrates push moraine formation. Boulton (1986, p.681) states that push moraines are common in maritime areas because glaciers, in these settings, have high ablation gradients and activity indices. These glaciers are readily affected by changes in mass balance brought about by relatively small changes in climate, sea level, and sea ice.

The rate of the initial glacial retreat within the paleo-Saint John River valley can be approximated from the sediments and C-14 dated material from Sheldon Point. Glacial ice was grounded at Sheldon Point until approximately 13 000 yBP and had retreated to the South Bay moraine by approximately 12 600 yBP. The interval of 400 years works out to a retreat rate of 10 m/yr (4000 m/400 yr). Retreat rates of 2500 to 3500 m/yr have been estimated along the southern and western boundary of the Laurentide ice sheet (S.R. Moran in Boulton, 1979; Clayton et al., 1985). The retreat rate in the Saint John region, therefore, is a relatively slow retreat.

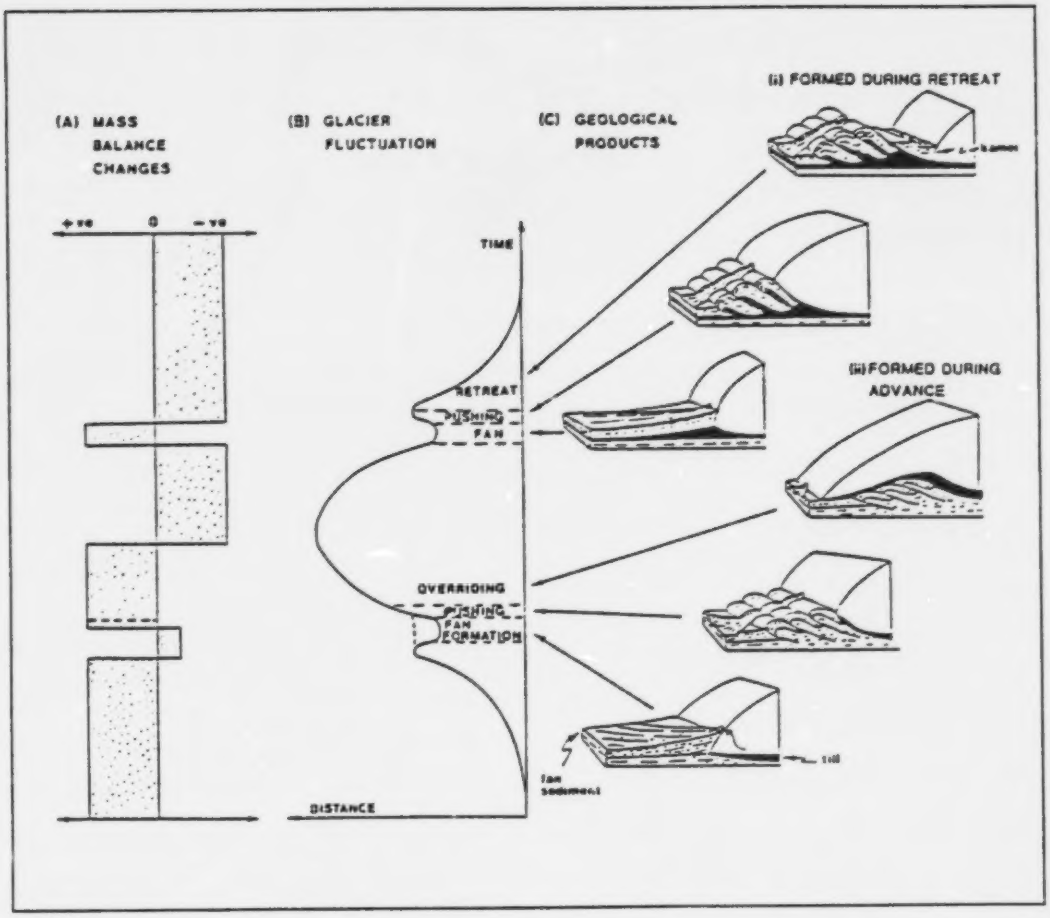


Figure 4.1. Figure from Boulton, (1986) (p. 695) illustrating the formation of large push moraines generated by ice contact fan formation followed by glacial advance.

These three moraines probably are the result of long term stillstands of an active, slowly retreating glacier with high ice velocity and calving rates (Boulton, 1986 and Facies Association II Powell, 1981). The similarity of the Sheldon Point moraine to the moraines described by Powell, (1981) suggests a temperate glacial environment.

Correlation of regional patterns of deglaciation

Regional climatic patterns have an effect on the mass balance of a glacier (Boulton, 1986). In maritime settings, relatively small climatic changes have a significant effect on the glacier margin. The dating control of the units within the Sheldon Point deposit, and the nature of sedimentation within these units suggest certain patterns of deglaciation for the Saint John region. These patterns are: 1) Glacial ice was grounded at Sheldon Point, until approximately 13 000 yBP. 2) Two re-advances occurred at approximately 12 650 ± 175 yBP and between 11 620 ± 175 yBP and 10 800 ± 120 yBP. 3) The glacier was grounded at Manawogonish moraine between 13 000 and 12 800 yBP (Unit 4) and had retreated to South Bay (Unit 5) by 12 600 yBP. 4) There was a depositional hiatus between approximately 12 500 and 11 500 yBP.

The Quaternary time period has been dominated by several major glacial and interglacial intervals and numerous small scale climatic variations. During glacials and interglacials, very large net transfers of mass occur between oceans and ice sheets. These mass transfers affect the environment and have a pronounced affect on the biota. Biota, such as pollen, beetles, microfossils and macrofossils are often good climatic indicators.

The use of biological evidence for the purpose of correlation and dating is a useful tool. There are some constraints, however, in utilising the fossil record for subdivision of glacial periods. For example, the repeated alternations of cooling and warming produce stratigraphic repetitions of certain species. The extinction or first appearance of a species is subject to the rate of migration, the constraints of the environment (Bowen, 1978, p. 137), and the length of the climatic event. For example, a relatively brief climatic event may not produce an equivalent evolutionary event in a fossil group.

At Sheldon Point, there is good stratigraphic control because of the number and location of C-14 dated shell samples. Fossil shell material collected from the Sheldon Point moraine should provide data on environment and climate. In addition, there have been a number of dated (conventional and accelerator C-14 dates) shell samples obtained for the Bay of Fundy region (Nova Scotia, southern New Brunswick and Maine). These dates represent a data base for the period 14 000-10 000 yBP for the Bay of Fundy region. A correlation was attempted between the shell samples and stratigraphy at Sheldon Point and the data from the Bay of Fundy region of Nova Scotia, southern New Brunswick, and southern Maine.

Biostratigraphy

The objective of this section is to establish a stratigraphic framework. It is based on the macrofossil data from Sheldon Point and the Bay of Fundy region and the lithologic units observed at Sheldon Point. A similar technique has been applied by Petersen (1984, 1986), Mangerud et al. (1981) and Boulton (1979) to establish a time, sea level and climatic framework. In addition, Wagner (1970) and Hillaire-Marcel (1980) completed studies of the fossils included in the Champlain Sea deposits. Many of the fossils observed in the Bay of Fundy region were also observed in the Champlain Sea. Hillaire-Marcel (1980) conducted a paleoecological study of the fossil fauna of the Champlain Sea of Quebec, with special attention to molluscs, and identified type communities. Figure 4.2 from Hillaire-Marcel (1980) illustrates the principal type communities of postglacial seas. These type communities will be used to infer climate and sea level for the Bay of Fundy region.

A histogram of the number of dated shell samples plotted against time was completed for the Maine, Nova Scotia, and New Brunswick coastlines. The data base (Table 4.1) was compiled primarily from four publications (Rampton et al., 1984; Stuiver and Borns, 1975; Smith, 1985; and Stea and Wightman, 1987). It was assumed that the shell samples were obtained randomly (i.e. the date was obtained without prior knowledge of the age of the shells).

Figure 4.3 contrasts the total sample data base (Bay of Fundy) against the southern New Brunswick and Maine data bases. The peak in the frequency distribution for southern New Brunswick is older than the peak for southern Maine. This may indicate that glacial ice had retreated to the coastline earlier in New Brunswick than in Maine. The Maine coast may have been subject to greater isostatic uplift than the New Brunswick coast so the elevation of shells from Maine cannot be used as sea level indicators for Sheldon Point and southern New Brunswick.

The total frequency distribution can be broken down

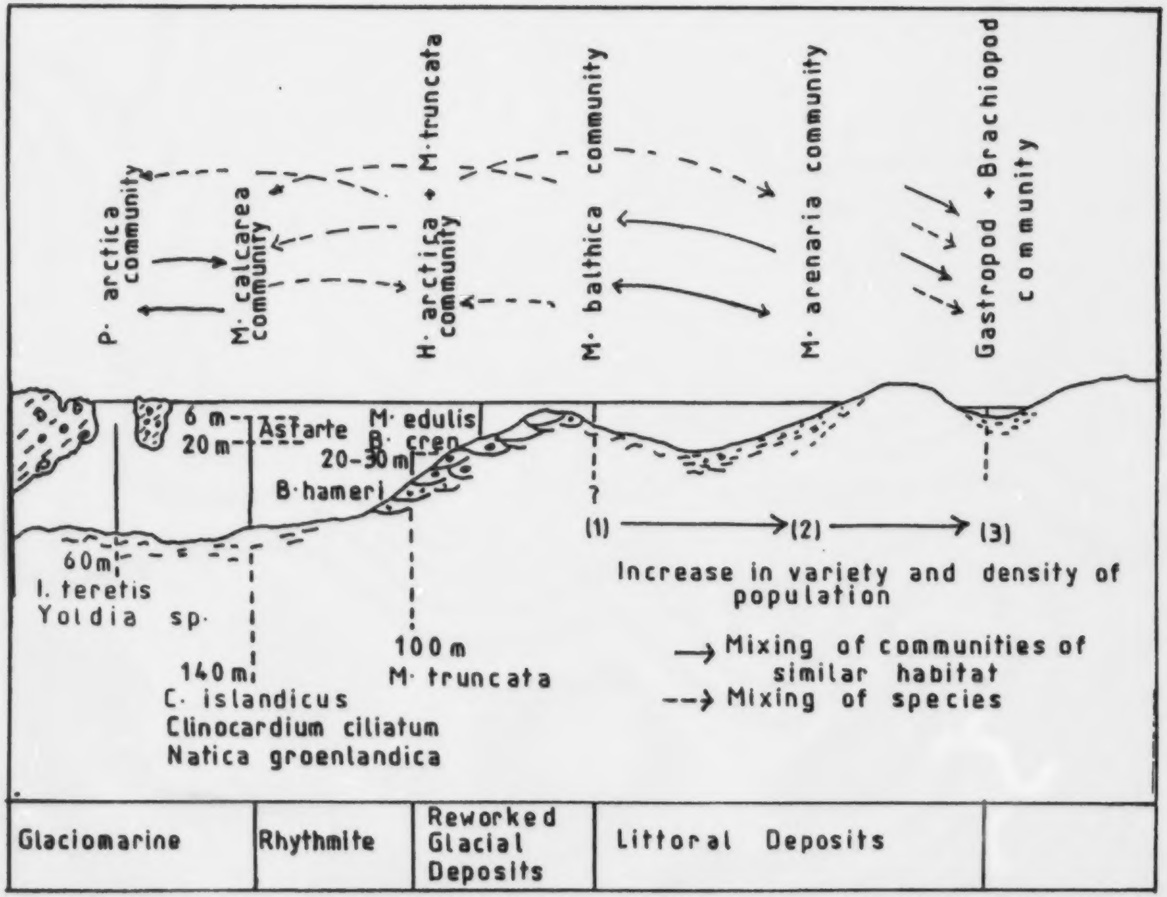


Figure 4.2. Figure from Hillaire-Marcel, (1980) illustrating the type communities of the post-glacial seas.

Table 4.1
Summary of Shell database

Lab No.	Date (yBP)	Error	Elev. (m)	Shells Identified
GSC 2573	14400	530	35	Ha
B12858	14300	320		Pa
GSC 3354	13900	620	45	Ha-small sample (Mt)
QL 192	13830	100		
B13728	13450	300		Pa
I(GSC)7	13325	500	3	marine shells (*Ro,Pa,Pf)
SI 4042	13230	360		
GSC 965	13200	200	6	Mc,Mt,Ha
Y 2208	13200	120	12	Ha,Ndt,B
GSC 3557	13100	160	45	Ha
GSC 2566	13100	130	30	Ba,(Mt,Ha,Cc,Macoma sp)
GX 13824	13070	370	35	Ha (
Y 1477	13020	240	125	Mb,Ha,B
GSC 2777	13000	330	4	Mc (Ha,Mt)
GSC 882	13000	240	40	Pa,Mb
GSC 3167	13000	200	30	Pa-siliqua (Ma,Mt,Mc,Ha,Ba,gastropods)
GSC 1340	13000	170	9	Mya sp,Ba,Sg,Mc
SI 4651	12905	110		
BGS 1174	12800	220	12	Me
GSC 3579	12800	140	30	Mya-sp,Mc
GSC 2640	12800	120	30	Mya sp (Pa,Cc,B,Ma)
Y 2214	12780	160	-3	B
GX 12871	12650	175	25	Me-articulated
B12859	12600	270		Pa
Y 2212	12560	160	55	Mc,Ma,Sg,Ndt,Bt,B
Y 2200	12530	180	3	Ne,Pa
Y 2203	12450	120	30	Me,Cl,B
SI 4649	12445	100		
Y 2207a	12440	120	40	Me,Mc,Sg,Nc,Mt,Ha
Y 2215	12400	140	27	?
Y 2209	12370	140	18	Ha,Mb
Y 2210	12350	140	37	Mt,Me,B,Ha,Pa,Ne
SI 4745b	12345	100		
Y 1473	12330	280	46	Mb,Ma,Pa,Ha,Mc
Y 1474	12320	160	45	Me,Mt,Ma,Ha,Mb,Tb,B
Y 1479	12320	160		
GSC 795	12300	160	15	Ha,Mc,Sg,Mt,B,Me,Lu,Np,Bu(*Sg,Mc,Mt,Bb)
GSC 888	12300	160	25	Me,Macoma sp
Y 2202	12280	100	43	As,Me,Mc,Mt,Nc,Ndt,Bt
Y 2213	12270	120	80	Me,Mc
Y 1475	12260	240	91	Mc,Mt,Ma,Me,Ha,Bps,B
Y 2206	12250	160	2	As,Cl,Ma,Mt,Me,B
Y 1775	12210	120	49	Ha,Ne,Mc,Me,Ma
Y 2205	12210	100	73	Me,Ha,Ne,Mc,B
SI 1048	12175	120	31	Me
Y 2211	12120	100	12	Ma,Mc,As,Bp,Cl,Me,Ne,B
L 678	12100	300	49	Me,Pya
BGS 1010	12040	150	12	B(Bc)
SI 3926	12040	105		
Y 2201a	12020	120	3	Me,Pa,As
W 947	11950	350	76	Me,Pya
SI 4745a	11920	110		
SI 4648	11900	100		
DIC 1596	11820	115		
W 737	11800	240	57	Me,Pya
DIC 1600	11760	105		Cl,Ha,Macoma,Mt,Me,Nc,Neptunea,Sg
DIC 1597	11730	95		
DIC 1599	11720	125		Me
DIC 1598	11700	115		
DIC 1591	11650	175		
DIC 1595	11640	115		
SI 4746b	11640	95		
BGS 1223	11620	250	37	Ha (Mp,Bt)
Y 1472b	11560	160	45	Ma,Me
SI 4746a	11510	270		
Y 2204b	11450	100	12	Mt,Me,Cl,As,B
SI 4747d	11450	90		
SI 4043	11355	125		
SI 4744b	10875	190		
Y 1472a	10520	140	45	Ma,Me
Y 2204a	10480	100	12	Mt,Me,Cl,As,B

Short forms

Ma- Mya arenaria (Linne)
Mt- Mya truncata
Mp- Mya pseudoarenaria
Mb- Macoma balthica (L.)
Ha- Hiatella arctica (L.)
Mc- Macoma calcarea (Gmelin)
Me- Mytilus edulis (L.)
As- Astarte arctica (Gray)
Cl- Chlamys islandicus
Ne- Nucula expansa (Reeve)
Sg- Serripes groenlandicus (Bruguiere)
Nc- Natica clausa (Broderip and Sowerby)
Bt- Buccinum tenue (G.)
As- Astarte subequilatera
Ndt- Neptunea despecta formata

Tb- Trichotropis borealis
Bp- Buccinum plectrum
B- Barnacles
Bb- Balanus balanus
Bc- Balanus crenatus
Bu- Buccinum sp.
Bs- Balanus sp.
Pa- Portlandia arctica (= Yoldia arctica)
Pya- Panomya arctica
Mp- Mya pseudoarenaria
Ro- Retusa obtusa
Pf- Portlandia frigida
Cc- Clinocardium ciliatum
**from Weisled samples at same location*
() indicates that other shells were included in the sample but were outdated.

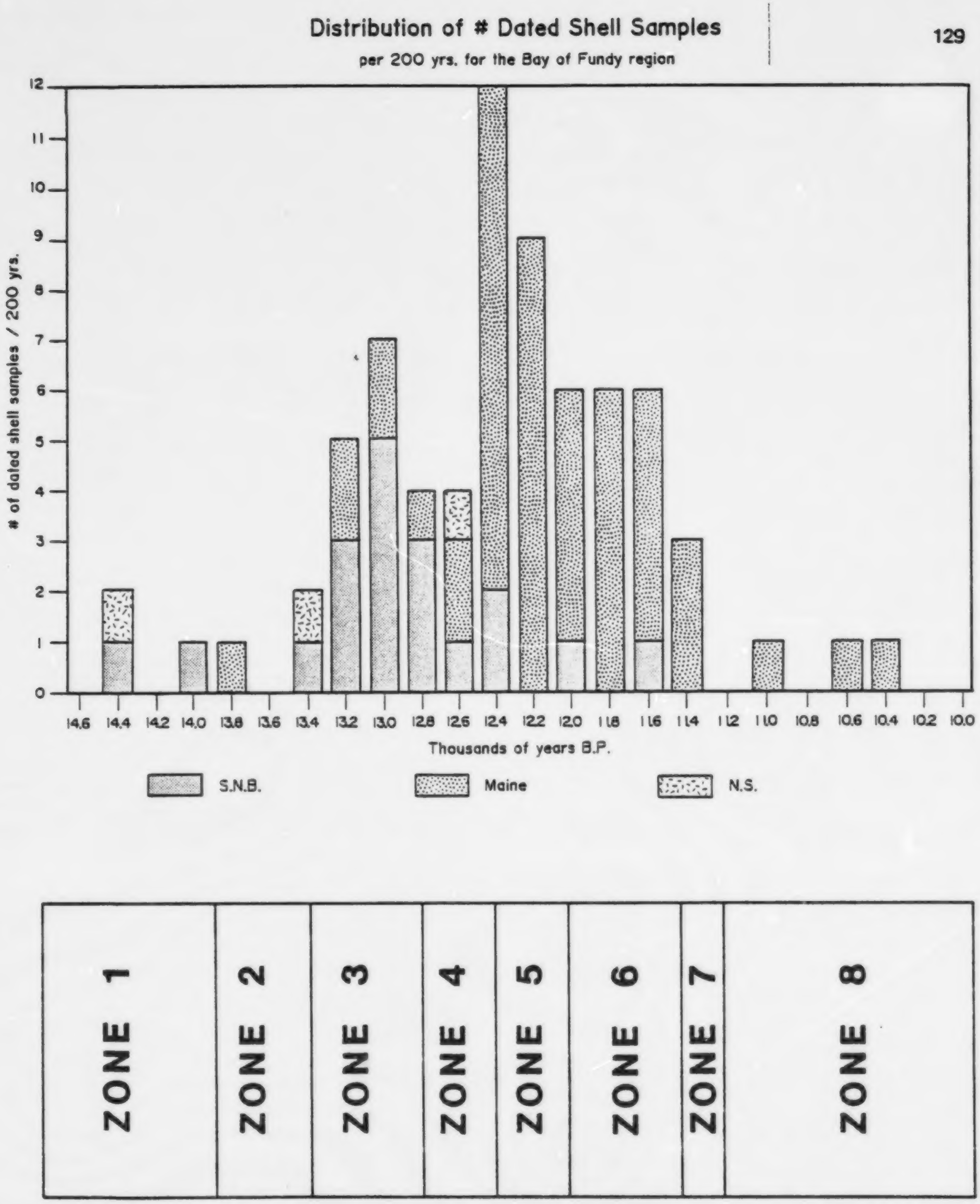


Figure 4.3 Histogram of the number of dated shell samples plotted against time for the Bay of Fundy-Gulf of Maine region.

into 8 zones based on statistical variations (Figure 4.3):

1) >14.0 2) 14.0-13.5 ka, 3) 13.5-12.9 ka, 4) 12.9-12.5 ka, 5) 12.5-12.1 ka, 6) 12.1-11.5 ka, 7) 11.5-11.3 ka, 8) 11.3-10.0 ka. There are significant changes in the macrofossil assemblages associated with the statistical variations and these zones will be referred to as "mollusc zones". The approach taken essentially contrasts the first appearance of a macrofossil with a change in the frequency distribution. The fossil evidence alone can not be used to identify a zone as the fossils are diverse. Generally, once the species appears, it remains throughout the record.

The first zone (Zone 1) is characterized by the absence of macrofossils and the presence of till. Since it is barren dates were not obtained from this zone. The date of its formation, therefore, can only be inferred to be older than the oldest dated shell material from the period of 14 400 ± 530 yBP. Because of the size of the error margin, this zone will be designated 14 000 yBP.

Zone 2 represents the period 14 000 to 13 500 yBP, when there is an initial sporadic range of dates. The oldest dated diamict (13 900 ± 620 yBP (GSC 3354)) from Sheldon Point occurred in this zone. This was the only dated sample at Sheldon Point from this zone. The zone is characterized by *H. arctica* and *P. arctica* shells.

H. arctica and *P. arctica* are arctic molluscs (Petersen, 1986) and probably represent the initial colonization by macrofossils. *H. arctica* is found in a wide range of water depths, however *P. arctica* is generally found in deeper water (>40 m) and on a mud bottom (Peterson, 1986). The only water depth that can be inferred for this zone is greater than 45 m a.s.l., this being the elevation at which the shells were recovered. The low diversity of macrofossils and limited number of samples probably indicates unfavourable ecological conditions. The presence of *P. arctica* suggests a location adjacent to an ice margin (Wagner, 1970). This interval probably represents the time when ice was initially grounded at Sheldon Point.

Zone 3 represents the time period of 13 500 - 12 900 yBP which is represented by the secondary peak in the frequency distribution. Five shell samples were obtained from the Sheldon Point deposit alone. In addition to *H. arctica* and *P. arctica*, *M. calcarea*, barnacles, *Neptunea despecta tornata*, *M. truncata*, *Clinocardium ciliatum* and *M. balthica* were the only shells found from this interval throughout the region. The diversification and increase in frequency suggest an amelioration in the oceanic and climatic conditions.

Wagner (1970) suggested that M. calcarea and M. balthica can tolerate salinities as low as 3.5-7 $^0/_{00}$. M. balthica and H. arctica are considered index species for the Champlain Sea sands and gravels (Wagner, 1970). M. balthica is a boreal species and does not penetrate Arctic waters (Wagner, 1970). M. calcarea is characteristically a cold water species (Wagner, 1970). The present northern limit of N. despecta tornata is the Gulf of St. Lawrence (Wagner, 1970).

Gadd (1973) reported that the foraminiferal species Quinqueloculina sp., and E. excavatum f. clavatum (=Elphidium incertum clavatum in Gadd, 1973) and Islandiella islandica, which generally indicate cold water marine conditions, and ostracods (interpreted to represent deposition in quite shallow, very cold frigid to sub-frigid water) were found with the dated shell material. The highest elevation (southern New Brunswick) at which dated shell material was obtained from zone 3 was 45 metres. This suggests that sea-level was higher than 45 m above present for this time interval. This corresponds with a previously published sea-level curve based on freshwater-marine transitions in nearby basins (Honig and Scott, 1987). This also corresponds to the sea-level curve of Belknap et al. (in press) in west central Maine.

This interval represents a time period when the tidewater glacier was fluctuating at Sheldon Point. As glacial ice retreated and re-advanced, it incorporated shell bearing marine sediments.

Zone 4 represents the interval from 12 900 - 12 500 yBP. There is a slight decrease in the frequency distribution during this time period. *Mya arenaria*, *M. edulis*, *S. groenlandicus*, *Nucula expansa* and *B. tenue* shells appeared for the first time. Barnacles, *P. arctica*, and *N. despecta tornata*, were also sampled.

Both *M. arenaria* and *M. edulis* are found in the intertidal zone to a depth of 30 m in temperate to boreal environments (Wagner, 1970). *M. arenaria* is commonly found in bays and estuaries. The remaining species are generally found in a wider range of shallow water depths (Peterson, 1986).

H. arctica and *M. truncata* samples were not recovered from this interval. These species cannot tolerate salinities less than 8 $^{0}/_{00}$ Wagner (1970). *M. arenaria* and *M. edulis*, however, are known to tolerate salinity as low as 5 $^{0}/_{00}$ (Wagner, 1970). *P. arctica*, which cannot tolerate salinity less than 20 $^{0}/_{00}$ (Wagner (1970)), is also found within this time interval. This may suggest that the shallow water depths (< 40 m), where *P. arctica* was probably absent, had reduced salinities. The presence of *P. arctica* with the other species may suggest a stratification of the water column, with an upper, less saline horizon and a lower horizon of normal salinity. High stratification of the water column is common in high latitude estuaries and offshore areas due to the hydrological cycle and the effects of seasonality (d'Anglejan in Syvitski, 1986).

Zone 5 represents the interval from 12 500 to 12 100 yBP, the primary peak on the histogram. Most of the shells collected during this interval are from Maine. There are, however, only two dates obtained from this interval at Sheldon Point. The majority of species observed in zones 1, 2, 3, and 4 are present. *Astarte subequilatera*, *Chlamys islandicus*, *Panomya arctica* and *Buccinum plectrum* were observed for the first time during this interval. *P. arctica* and *B. plectrum* occurred within the error margin of this zone and Zone 6. *H. arctica* and *M. truncata*, not sampled in zone 4, were also sampled in this zone. Some of the other shells documented in this interval are *M. calcarea*, *M. arenaria*, *S. groenlandicus*, *N. despecta tornata*, *B. tenue*, barnacles, *P. arctica*, and *C. islandicus*.

Mangerud et al., (1981) state that *C. islandicus* is most common at depths between 7 and 30 m. *C. islandicus* requires for spawning a fjord surface water layer characterized by positive temperatures during a part of the year. This suggests that during this time period, there was not a year round sea ice cover. B. plectrum is common in offshore waters today and ranges from the Arctic to the Gulf of St. Lawrence (Wagner, 1970)

Zone 6 represents the time interval between 12 100 and 11 500 yBP. The histogram shows a drop in the frequency of shells from Zone 5, and the histogram levels off. The shell species were largely undocumented in the literature during this interval. The identified shells were M. edulis, P. arctica, A. subequilatera, P. arctica, C. islandicus, M. truncata, barnacles, and H. arctica . These are similar to the species observed in Zone 5. It would appear that there is a general reduction in diversity of macrofossils.

Zone 7 represents the time interval from 11 500 - 11 000 yBP. There was only one dated shell from this interval and it was from Maine. There was no published information available on the species dated. This interval represents the time period when sea-level at Sheldon Point fell from approximately 40 m a.s.l. to approximately 10 m a.s.l.

Zone 8 represents the time interval from 11 000 to 10 000 yBP. There are very few dated macrofossils from this interval and there is no dated shell material from southern New Brunswick. There were, however, three shell dates obtained in Maine for this time interval. The samples contained M. arenaria, M. edulis, M.

truncata, C. islandicus, A. subequilatera and barnacles, which are an assemblage similar to **Zone 5** with the exception of M. truncata. Several dates have been obtained from a peat layer at Sheldon Point at approximately 10 m. a.s.l. Dates obtained on the peat ranged from 10 800 ± 110 to 10 500 ± 200 yBP and indicate that sea-level fell below 10 m. a.s.l. at Sheldon Point, prior to 10 800 ± 110 yBP. This zone marks the approximate end of elevated sea-levels and glacial marine deposition at Sheldon Point.

Comparisons

On a histogram of the distribution of the number of shells versus time in years before present, certain trends became apparent (Figure 4.3). The frequency of shell dates compiled from New Brunswick samples peaks at approximately 13 000 yBP. The frequency of shell dates compiled from Maine peaks at 12 400 yBP. The greatest peak in the distribution is 12 400 yBP. Data are sparse between 14 500 and 13 500 yBP and again between 11 300 and 10 000 yBP. At 13 000 yBP, the ice was fluctuating and retreating at Sheldon Point. There was a depositional hiatus at Sheldon Point between 12 600 and 11 600 yBP (± 200 years) which has been interpreted as a retreat of the ice from the marine environment.

The peaks in the histogram, therefore, correspond to retreats of the ice. Furthermore, there are three significant decreases in the number of samples between 12.9 and 12.5 ka, 12.1 and 11.5 ka, and 11.5 and 10.0 ka yBP. At Sheldon Point, two re-advances of glacial ice occurred between 12.9 and 12.5 ka and between 11.5 and 11.0 ka. There is some indication that the frequency distribution of the dated shell samples can be correlated with climate and/or sea-level. In addition, the apparent correlation of Sheldon Point events with the regional distribution of shell samples implies a regional correlation of events.

To determine if the distribution is reflecting climate, the results were compared to other data bases.

New Brunswick

Changes in the shell frequency distribution resemble the six phases 1) Chignecto (14.0-13.5 ka), 2) Bantalor (13.5-12.7 ka), 3) Millville/Dungarvon (12.7-12.3), 4) Plaster Rock (12.3-12.0 ka) and Chaleur, and 5) Madawaska (12.0-11.7 ka) identified by Rampton et al. (1984) for New Brunswick (Figure 4.4).

Mott (1975, p.285) identified several pollen zones for southwestern New Brunswick and a summary is presented (Figure 4.4). Following the retreat of the

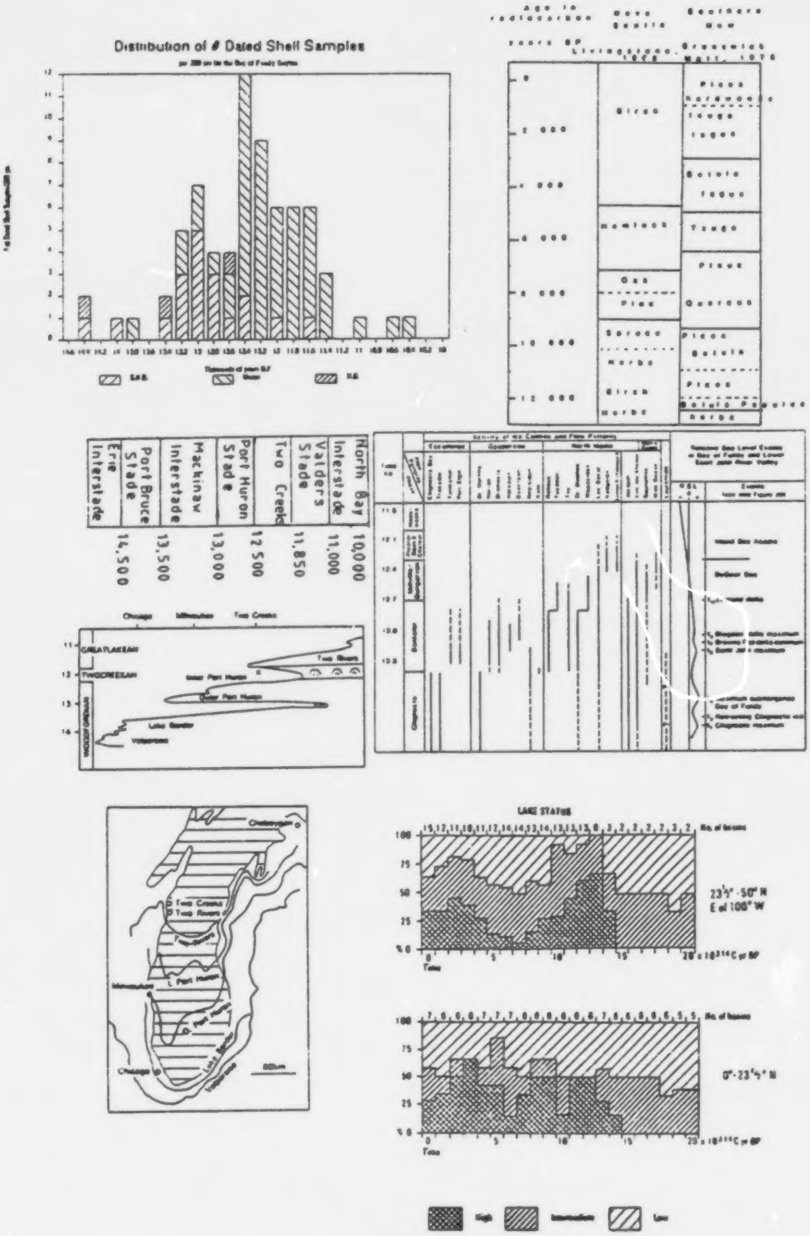


Figure 4.4. Figure contrasts the shell histogram of Figure 4.3 with the phases identified by Rampton et al., (1984), the pollen zones identified by Mott, (1975) for southern New Brunswick, the time-stratigraphic classification in the Great Lakes region, and the histograms of the lake level variations identified by Harrison and Metcalfe, (1985). Note the low lake levels of both the tropical (0-23 N) and eastern United States (23.5-50 W. This suggests that the climate was dry south of the glacier margin during the glacial maxima (Harrison and Metcalfe, 1985).

ice, the newly exposed landscape became vegetated by shrubs and herbs, many of which have modern tundra affinities. Trees were absent. At approximately 12 600 yBP birch (Betula) and poplar (Populus), most likely a dwarf birch and aspen poplar, became more abundant. By 12 000 yBP spruce had migrated into the area, formed open woodlands and reached a peak at approximately 11 300 yBP. By 11 000 yBP, spruce (Picea) declined and birch, aspen, and some non-arboreal taxa increased. Absolute pollen frequencies and accumulation rates show that the area was open and not completely tree covered until about 9500 yBP. Mott et al. (1986) examined organic deposits, C-14 dated between 11 000 and 12 000 yBP, sandwiched between inorganic layers. The authors inferred that vegetation grew in shallow depressions during a warm interval between 11 000 and 12 000 yBP and were covered by inorganic sediments when colder conditions returned at approximately 11 000 yBP. Mott et al. (1986) correlate this cooling event to the "Younger Dryas" oscillation in western Europe. In summary, there were four pollen assemblage biozones recognized: 1) 13 000-12 600 yBP (tundra), 2) 12 600-12 000 yBP (Betula-Poplar), 3) 12 000-11 000 yBP (Picea), and 4) 11 000-10 000 yBP (barren). There is a broad correlation between the macrofossil and pollen biozones. The peat at Sheldon Point was dated between 10 800 and

10 500 yBP and Mott (personal communication) interprets the pollen assemblage biozone as indication of a cooling event.

On a regional scale, the pollen assemblage biozones and mollusc zones appear to correlate with inferred climatic events from the Great Lakes region. These climatic events are stades and interstades that are well documented in the Great Lakes region (Fullerton, 1980). Figure 4.4 contrasts the mollusc zones and the pollen assemblage biozones against a correlation chart from Fullerton (1980) for the Great Lakes region.

In addition, Harrison and Metcalfe (1985) have reconstructed the temporal sequence of hydrological fluctuations in 67 North American closed lake basins. They have interpreted the changes in [illegible] status in North America as an indication of the displacements of circulation patterns, specifically the zonal Westerlies and the Equatorial Trough. Histograms of the lake status from the eastern half of North America from 20 000 yBP to the present are included in Figure 4.4. Harrison and Metcalfe (1985) found a broad similarity between the eastern mid-latitudes and the tropics. They inferred that moist air from the Gulf of Mexico penetrated north. This was a result of a weakening of the zonal circulation and a northward displacement of the Arctic Front. The major displacement of the Arctic

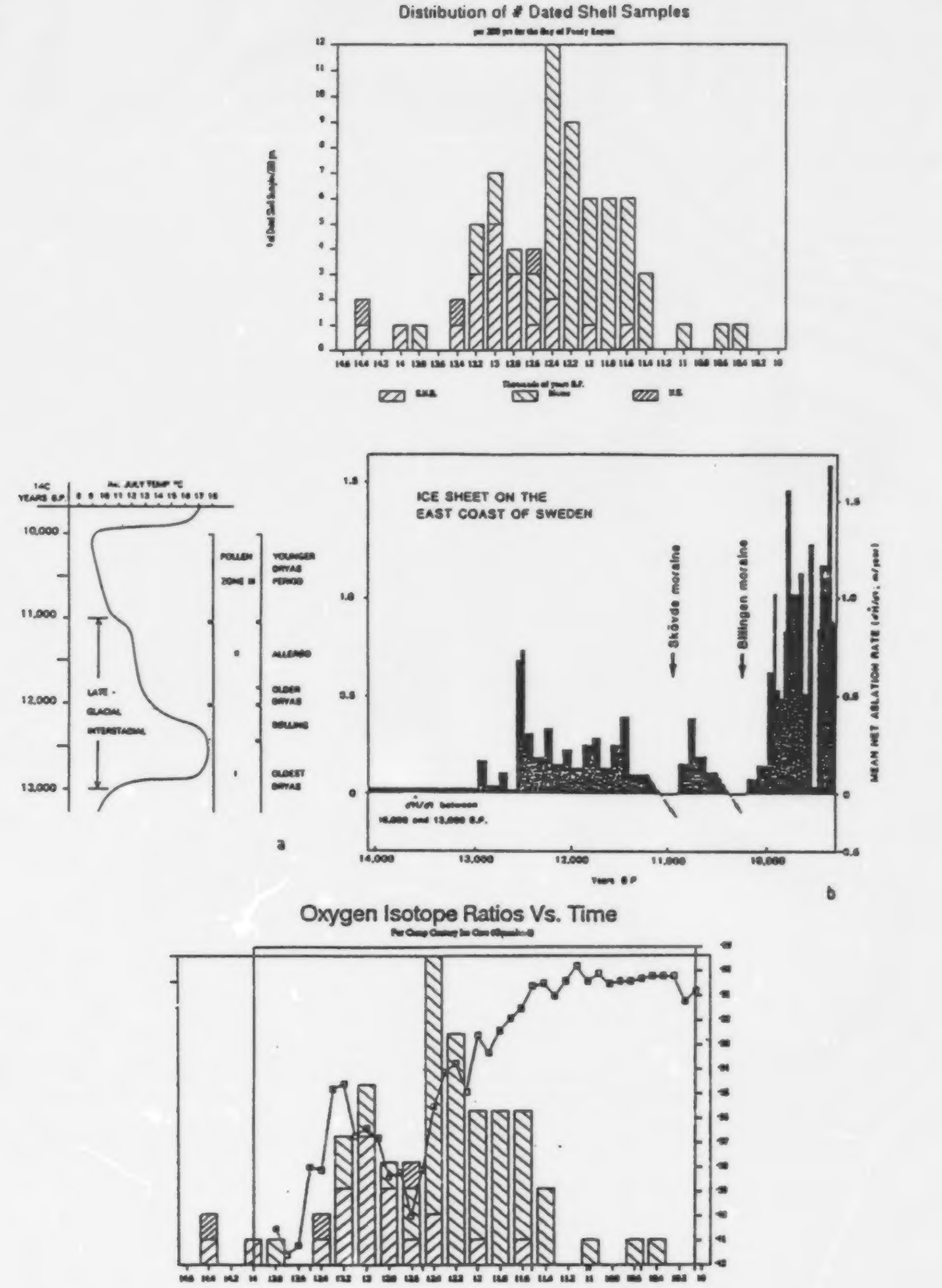


Figure 4.5. Contrasts the shell histogram from figure 4.4 with information on climate in a) Europe (Late-glacial temperatures from coleoptera from Coope (in Bowen, 1978, p. 149)) b) Sweden from varve chronology (Boulton, 1985) and oxygen isotope data from Greenland (Dansgaard et al., 1971) during the late Wisconsinan glaciation. All data indicate a warm interval at approximately 12,500 yBP and a cooling interval at 10,000 and 11,000 yBP

front followed a period of rapid recession of the Laurentide Ice Sheet (after 14 000 yBP). There is evidence, in the tropics histogram, of a southward displacement of the Arctic Front at approximately 10 000-11 000 yBP.

The interpretation by Harrison and Metcalfe (1985) is similar to the climatic record of the mid-latitude North Atlantic plankton record described by Ruddiman and M^{c}Intyre (1981). The results of Ruddiman and M^{c}Intyre, (1981) correlate with climatic changes observed in the offshore and maritime areas of Europe. Ruddiman and M^{c}Intyre (1981) place the polar front far to the south, at approximately 45° N over the north Atlantic, during the interval of 20 000 to 13 000 yBP. They suggest that the interval 16 000-13 000 yBP marked the most rapid delivery of meltwater and icebergs to the subpolar North Atlantic during the last deglaciation. They further suggest that the ice was grounded at its perimeter, below sea-level, which allowed the rapid ablation of the ice sheet margins. Rapid ablation was explained by a positive feedback loop initiated by increased summer insolation on the southern terrestrial margins of the North American and European ice sheets which decreased the continental ice volume. The decreased continental ice volume increased meltwater production, raising sea-level which in turn increased the attack on the land ice. The net effect was a period of rapid drawdown of the large continental ice sheets. This caused the rapid disintegration of approximately 50% of the ice sheet by 13 000 yBP. Ruddiman and M^{c}Intyre (1981) further proposed that the rapid meltwater influx created conditions favourable for winter freezing of the North Atlantic (cold surface waters and reduced salinity).

The mollusc zones are similar to climatologic zones observed in Europe, North America, and Greenland (Figure 4.5). In a broad sense, the data coincide with the polar shifts described by Ruddiman and M^{c}Intyre (1981). This suggests that the macrofossil zones reflect climatic and oceanographic conditions.

The comparison of mollusc zones from the Bay of Fundy region and Sheldon Point Unit interpretations is illustrated in Table 4.2.

A Model for the Formation of Shallow Water Tidewater Glacier Moraines

Glaciomarine environments are poorly understood because of the inaccessibility of modern tidewater glaciers and Quaternary deposits below sea-level. Many models of glaciomarine sedimentation are based on the classic polar model presented by Carey and Ahmad (1961). The King and Fader (1986) model, the current model for

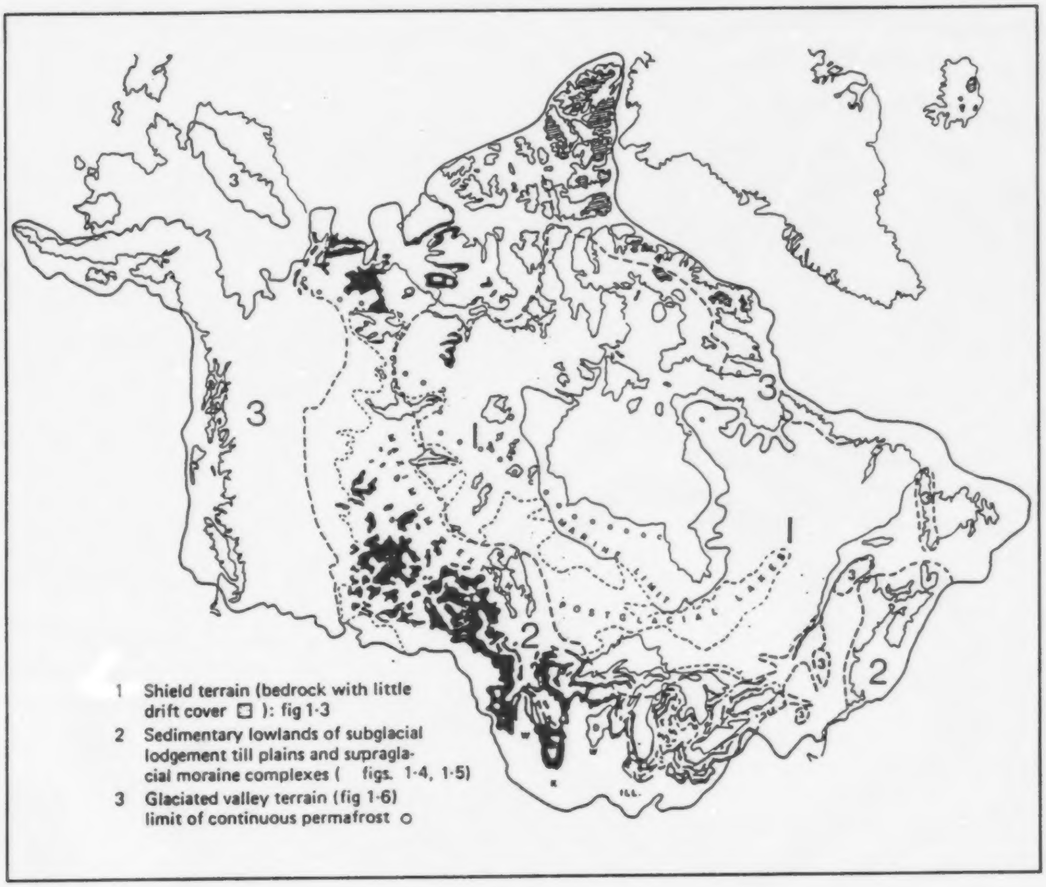

3
3
3
1
1
2
2
MARINE LIMIT
POSTGLACIAL LAKES
ILL.
1 Shield terrain (bedrock with little drift cover ▢): fig 1·3
2 Sedimentary lowlands of subglacial lodgement till plains and supraglacial moraine complexes (figs. 1·4, 1·5)
3 Glaciated valley terrain (fig 1·6)
limit of continuous permafrost ○

Figure 4.6. Figure from Eyles, (1984) (p.215) illustrating glacial landsystems in North America.

Table 4.2

Summary of dated material and the associated Units at Sheldon Point.

Zone	Age	Shell Assemblage	Units	Interpretation
1	14 000	Barren	Unit 1	-Position of ice unknown, probably along the coastline
2	14 000-13 500	Ha, Pa	Unit 1	-Glacial ice is grounded at Sheldon Point
3	13 500-12 900	Ha, Pa, Mc, Mt, Ndt, B, Ba, Cc, Mb	Unit 1, 2, 3, 4	-Glacial ice is fluctuating, creating an ice push moraine
4	12 900-12 500	Me, Ma, B, Sg, Bt, Pa, Mc	Unit 5, 6, 7	-Ice retreats to Manawogonish moraine, then South Bay moraine; ice readvances from north-west
5	12 500-12 100	Ci, Nc, As, Ne, BP, Pya, Me, Mc, Sg, Mt, Mb, Ha, B, Pa, Sg, Ma	Depositional hiatus	-Marine deposition associated with a land based glacier
6	12 100-11 500	B, Me, Pa, As, Pya, Ci, Ha, Mt, Ma	Depositional hiatus-base of Unit 8	-Marine deposition; ice readvances at the close of this interval
7	11 500-11 000	Mt, Mc, Ci, As, B,	Unit 8, Unit 9	-Glacial ice readvances to the Saint John Harbour region and deposits ice-contact gravel at Sheldon Point
8	11 000-10 000	Ma, Me, Mt, Ci, As, B	Unit 9, Peat	-cool interval indicated by regional pollen data and the pollen analysis completed on the peat at Sheldon Point.

the Bay of Fundy region and the offshore areas of Nova Scotia is derived from this model. Molnia (1983) stated that (p.96):

> This polar system (Antarctic), although presently the largest glacial system on Earth, is not an ideal system to use as a basis for defining glacial-marine sedimentation as (1) it generally lacks a meltwater component and therefore also lacks many of the facies that result in subarctic glacier systems; (2) the continental margin where much of the Antarctic glacial-marine sediment is deposited, is much deeper, steeper, and opposite in direction of slope to any other glaciated present day margin; and (3) it may not be indicative of the majority of glacial environments that have existed throughout geologic time.
>
> As a result of these characteristics, the end product of Antarctic glacial-marine sedimentation is more limited in variety of facies and character of deposits, and different in type of reworking than glacial-marine environments of other regions...

Molnia (1983) proposed a model for subarctic glaciomarine sedimentation based on studies completed in the Gulf of Alaska. He further suggested that the Gulf of Alaska may be more representative of mid-latitude glaciomarine sedimentation than the Antarctic. Molnia (1983, p.137) found that glaciofluvial input is the single most important mechanism responsible for deposition in subarctic glaciomarine environments. Similar models have been presented for the west coast areas as far south as Washington by Domack (1983), Powell (1981 and 1983) and in Europe by Boulton (1982, 1986) and Elverhoi and Seland (1983). Balzarini (1983) used microfossil and macrofossil data to reconstruct the late glacial marine environment of the Puget Lowland region and inferred a subarctic environment during glaciation.

The Puget Lowland was studied because the sediments were deposited in a shallow marine environment and are now well exposed due to isostatic uplift and glacial erosion. The Puget Lowlands have similar sediments, microfossils, and macrofossils as the Bay of Fundy-Gulf of Maine region. The units outlined in this thesis are very similar to the facies for a slowly retreating, tidewater glacier grounded in shallow water described by Powell (1981). This suggests that a subarctic glacial environment existed during the period of deposition outlined in this thesis for the southern New Brunswick area. The similarity of microfossil and macrofossil data from the Gulf of Maine and Bay of Fundy region to that of Balzarini (1983) also supports this proposition. In addition, a temperate climatic regime has already been suggested by Scott and Medioli (1980), Scott et al. (1984) and Honig and Scott (1987) for the eastern offshore region. The Sheldon Point moraine, therefore, may provide the basis for a temperate tidewater glacial model and may be applicable for some east coast offshore deposits.

Boulton (1979) observed an association between glacial landsystems and bedrock lithology and developed a theory in which the glacier profile is related to the hydraulic and strength properties of the underlying, potentially deformable, sediments or bedrock. Boulton (1979, p. 29) explained:

> If these (bed materials) have a high hydraulic transmissibility, melt water is readily discharged subglacially, the bed is stable, and the profile is a normal parabolic one, governed by the rheological properties of ice. If bed transmissibility is low, water pressures build up, the bed begins to deform, and a lower equilibrium profile will develop, so that in an extreme case the glacier approximates to a thin flat sheet, similar to an ice shelf.

Figure 4.6 from Eyles (1984) illustrates the different forms in moraine formation in North America along the southern boundary of the Precambrian shield. The same contrast is apparent on the continental shelves of eastern Canada (Figure 4.7). The Scotian Moraine Complex forms a linear belt parallel to the bedrock contact between the bedrock of the Meguma Group and the semi-consolidated Tertiary and Cretaceous bedrock (King and Fader, 1986) of the Scotian Shelf. The moraines are lobate, similar to those in the Great Lakes region, in the areas underlain by Tertiary or Cretaceous semi-consolidated bedrock. Erosion is also pronounced along these bedrock boundaries. For example, the Great Lakes, Lake Winnipeg, Great Slave Lake and Great Bear Lake, are glacially eroded basins similar to LaHave Basin, Emerald Basin, and Roseway Basin. The broad similarities in landsystems between these areas suggest that similar

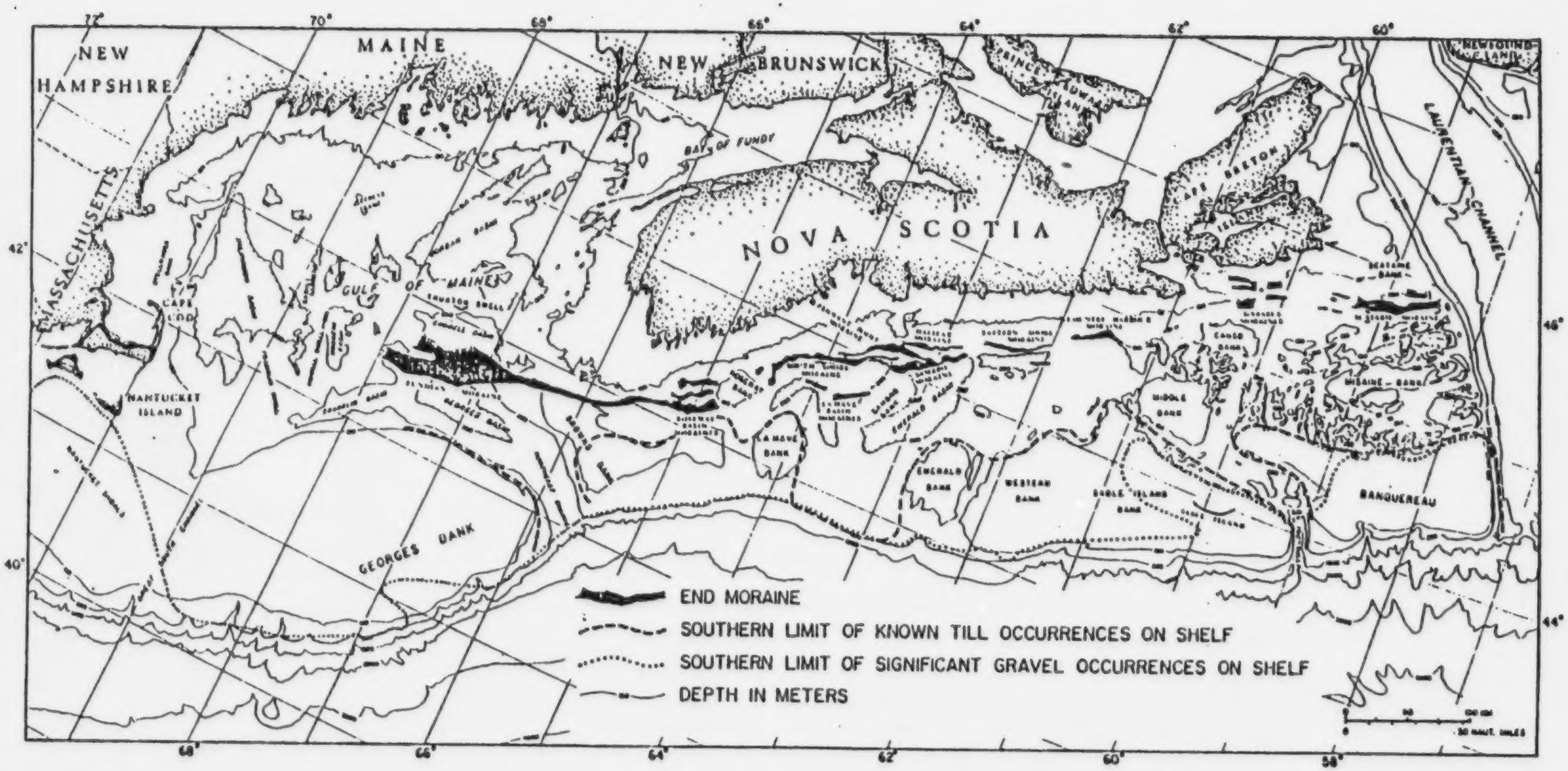


Figure 4.7. Illustration of the moraines on the Scotian Shelf (King and Fader, 1986)

processes may be responsible for the erosion and deposition of sediment on the Scotian Shelf. This landsystem evaluation also suggests that the polar glacial model suggested by King and Fader (1986) may not be the most applicable model for the southern shallow east coast offshore areas of Canada. In addition, recent work by Boyd et al. (1988) illustrates the predominance of meltwater tunnels in the Sable Island region of the Scotian Shelf. The presence of these large meltwater systems suggests a subarctic environment (Molnia, 1983). Gipp (1988) has described iceberg scours from Facies A Emerald Silt, which suggests that an ice shelf may not have been present.

If the bedrock model proposed by Boulton (1979) and Boulton et al. (1985) can be used as a basis for a model for the east coast offshore region, the Sheldon Point moraine may be useful as a basis for a model for some areas on the Scotian Shelf. The large Scotian Shelf moraine complex which parallels the Meguma bedrock contact, may be similar to the Sheldon Point moraine because of the impermeable nature of the bedrock in both areas. Large scale push moraine formation is favoured adjacent to meltwater conduits because of the formation of ice contact fans (Boulton, 1986; Powell, 1981) and deposition is controlled, primarily, by the rate of meltwater in-flow. As the ice thinned and retreated, small scale re-advances may have occurred with limited evidence of re-advance as seen at Sheldon Point. Short and medium term glacial fluctuations would have been controlled by surging and/or changes in mass balance which are created by large and small fluctuations in climate, sea-level, sea ice conditions, and glacier morphology. Therefore, if the Sheldon Point moraine can be used as a basis for a model for some deposits on the Scotian Shelf and Bay of Fundy region, it is possible that some of these moraines are compound moraines, representing more than one glacial margin position.

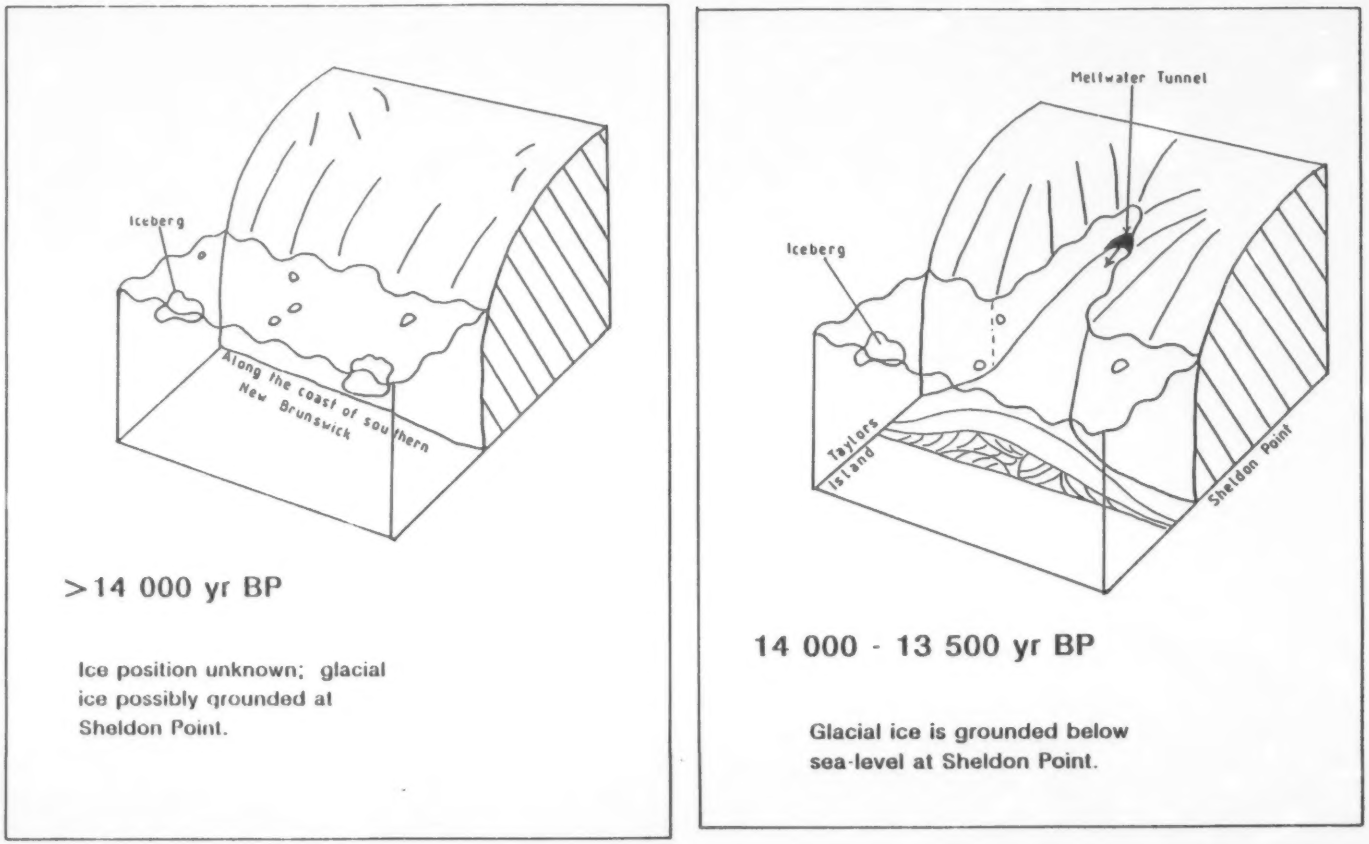
CHAPTER 5

CONCLUSIONS

The Sheldon Point moraine records the nature of sedimentation between 14 000 and 10 000 yBP. In eastern Canada, the ice had retreated to the coastline by the late stages of glaciation (Stea and Wightman, 1987). At this time, the glacier had thinned and would have been more susceptible to smaller climatic oscillations and sea level variations as interpreted in Chapter 4. Any major sea level change or climatic event would have affected the mass balance of the glacier. The presence of the moraine would have acted as a nucleus for subsequent re-advances. The Sheldon Point moraine is a compound moraine representing at least two re-advances of the glacier. The subsequent re-advances produced much smaller features and probably did not alter the configuration of the original moraine. It is important, therefore, to note that the Sheldon Point moraine represents more than one end moraine position.

The depositional record recorded by the Sheldon Point moraine is as follows:

1) Stea and Wightman, (1987) proposed that the Bay of Fundy became free of glacial ice about 14 000 yBP (Figure 5.1). The difference in the frequency of dated shell samples between Maine and southern New Brunswick



>14 000 yr BP

Ice position unknown; glacial ice possibly grounded at Sheldon Point.

14 000 - 13 500 yr BP

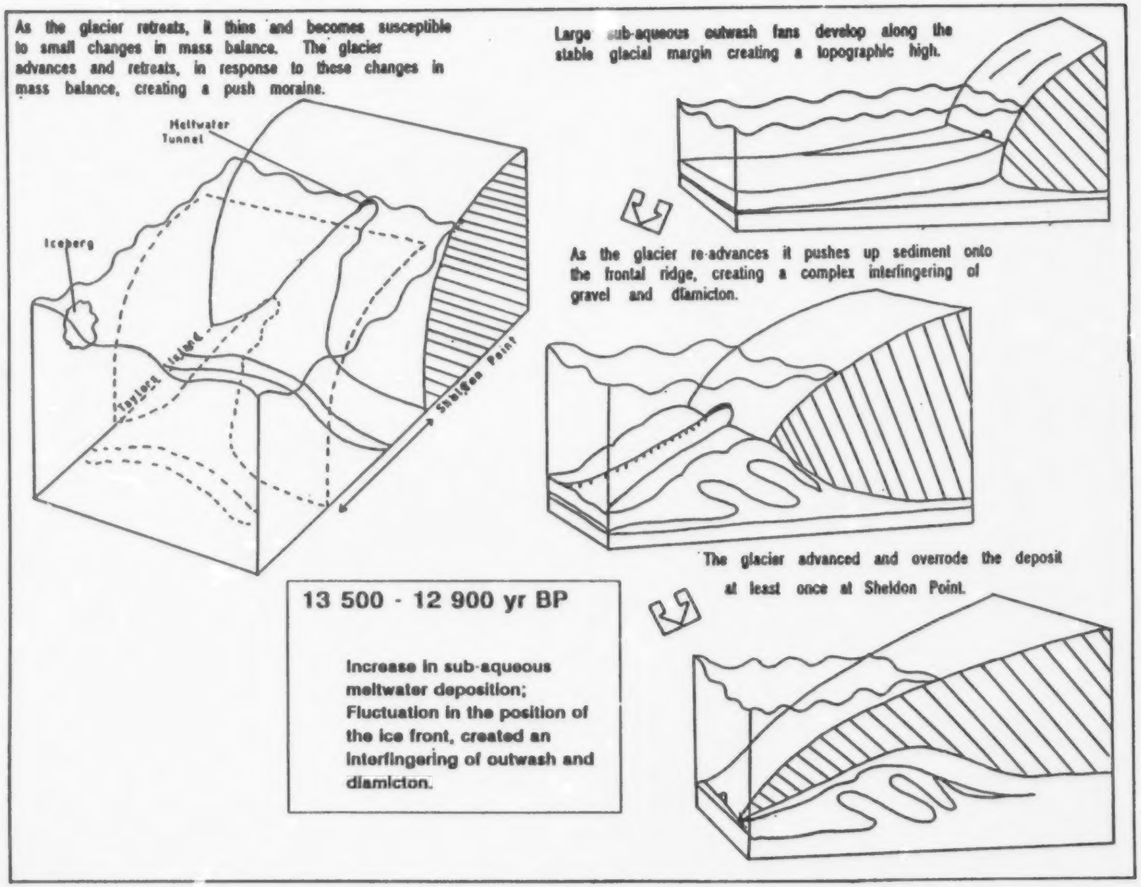
Glacial ice is grounded below sea-level at Sheldon Point.

Figure 5.1. Location of the ice in southern New Brunswick at approximately 14,000 yBP and depositional environment between 14,000 and 13,500 yBP (diagram derived from Cheel and Rust, 1980).

suggests that the head of the bay was ice free earlier than the Gulf of Maine region.

2) Glacial ice was grounded at Sheldon Point from 14 000 to 13 500 yBP. The deposition of the non-fossil bearing sediments in the lowest part of the deposit probably occurred during this time period (Figure 5.1).

3) The peak in the frequency of the number of dated shell samples (Figure 4.3) in southern New Brunswick between 13 500 and 12 900 yBP combined with the dated glaciofluvial gravel and diamict, suggest that an amelioration in the climate, coupled with elevated sea level, caused increased ablation of the glacier. The increased ablation would have created a fresh surface water that was susceptible to freezing in winter, creating winter sea ice. The sea ice would have stabilized the glacier during winter and created surging conditions during summer break up. The combination of seasonal factors and longer term variations in mass balance created a fluctuating ice margin at Sheldon Point during this time interval (Figure 5.2). The fluctuations created an interfingering of subaqueous outwash gravel with till and diamict (Unit 1). The upper reddish-brown diamict could have been formed by a number of processes and the lower greyish-brown diamict is probably a till (both diamicts are from Unit 1). Unit 2 represents proglacial, subaqueous meltwater



As the glacier retreats, it thins and becomes susceptible to small changes in mass balance. The glacier advances and retreats, in response to these changes in mass balance, creating a push moraine.

Large sub-aqueous outwash fans develop along the stable glacial margin creating a topographic high.

As the glacier re-advances it pushes up sediment onto the frontal ridge, creating a complex interfingering of gravel and diamicton.

The glacier advanced and overrode the deposit at least once at Sheldon Point.

13 500 - 12 900 yr BP

Increase in sub-aqueous meltwater deposition; Fluctuation in the position of the ice front, created an interfingering of outwash and diamicton.

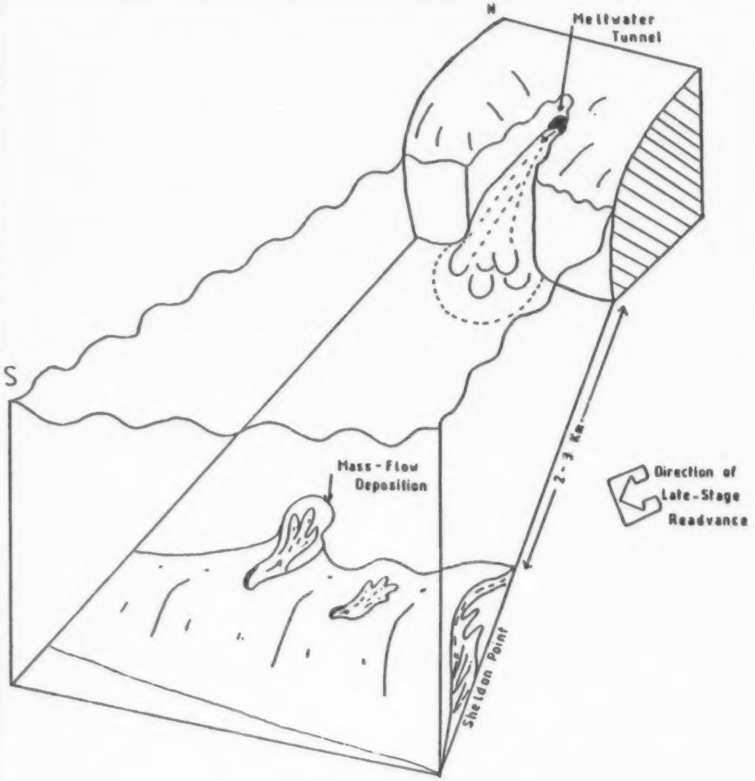
Figure 5.2. Diagram of the depositional environment between 13,500 and 12,900 yBP (partially derived from Boulton, 1986)

deposition and was likely formed during this interval. Units 1 and 4 contained shells which were dated during this interval.

4) The ice retreat was followed by destabilization of the ice contact slope and mass flow deposition (Units 3 & 4). The glacial ice probably retreated up the Saint John River paleovalley to the Manawogonish moraine. No dates, however, have been obtained from the Manawogonish moraine (Figure 5.3).

5) The decrease in frequency distribution (Figure 4.3) during the period of 12 900 and 12 500 yBP, combined with the climatic data presented in Chapter 4, suggests a cold period. The only dated shell material at Sheldon Point during this interval was from Unit 6, which has been interpreted as mass flow deposition, proximal to an ice margin. This suggests a re-advance of the ice from the northeast.

6) The primary peak in the frequency distribution of dated shell samples for the interval 12 500-12 100 yBP, suggests a warming of the waters of the Bay of Fundy leading to diversification and increase in the population of macrofossils. This suggests an amelioration in the climate. At Sheldon Point, there appears to be a depositional hiatus. The only recorded shell material was from barnacles anchored on bedrock. A period of non-deposition suggests that glacial ice had



12 900 - 12 500 yr BP

Initially glacial ice had retreated 2 - 3 km north of Sheldon Point. Deposition at Sheldon Point was dominated by proximal, pro-glacial marine processes. Mass flow deposition occurred on the oversteepened north side of the deposit.

Ice proximal gravel and ice thrust features indicate a re-advance of the glacier. Thrust features indicate a southwest flow at the close of this time zone.

Figure 5.3. Illustration of the depositional environment between 12,900 and 12,500 yBP.

retreated from the sea. It is suggested that the ice was grounded at the South Bay moraine but was not exposed to the ocean. Well defined beach ridges can be observed on the south side of the Manawogonish moraine (Figure 1.12) but are absent on the South Bay moraine. The north face of the Manawogonish moraine is sharp and has a well defined ice contact face. This suggests that sea level was lower than the moraine, while the ice was grounded at the Manawogonish moraine. The massive, fine grained nature of Unit 5 suggests cold-water marine rather than glaciomarine sedimentation. The crest of the moraine is approximately 60 m a.s.l. It is proposed, therefore, that the Manawogonish moraine dammed the sea from the southern portion of the Saint John River paleovalley.

7) There is a decrease in the frequency distribution of dated shell samples between 12 100-11 300 yBP which is interpreted as a climatic cooling event. There is one date from Sheldon Point during this interval. It was obtained from shell material at the base of Unit 8. Foraminiferal analysis indicates normal marine conditions, however the absence of pollen indicates glacial conditions.

8) There is a dramatic decrease in the frequency distribution between 11 300-11 000 yBP which has been interpreted as a re-advance of the glacier into the

marine environment. The overall form, visible from aerial photographs, and the composition of the sediments of Unit 8 suggest glaciofluvial deposition. The base of the unit was folded suggesting that glacial ice may have re-advanced during this period. The flow direction is northward, suggesting an ice source to the south. There is limited evidence to suggest a re-advance from the Courtney Bay area which could have filled the harbour with glacial ice. The upper surface of Unit 8 is flat lying and suggests that sea level was approximately at this elevation (40-45 m) during deposition. Sea level must have fallen quite rapidly, to expose the area where the peat was formed at 10 m a.s.l. by 10 800 yr BP.

The study suggests that the Laurentide ice was not present during the late stages of deglaciation (later than 14 000 yBP) in southern New Brunswick. The succession of deposition at Sheldon Point suggests that glacial ice retreated slowly from the Sheldon Point area between 13 500 and 12 500 (Figure 5.4). Local ice centres were present, possibly in the highland areas, from 12 500 to 10 500. This order of ice retreat from southern New Brunswick contradicts the succession presented by Rampton et al. (1984) who suggested that glacial ice had retreated from southern New Brunswick between 12 800 and 12 600 yBP.

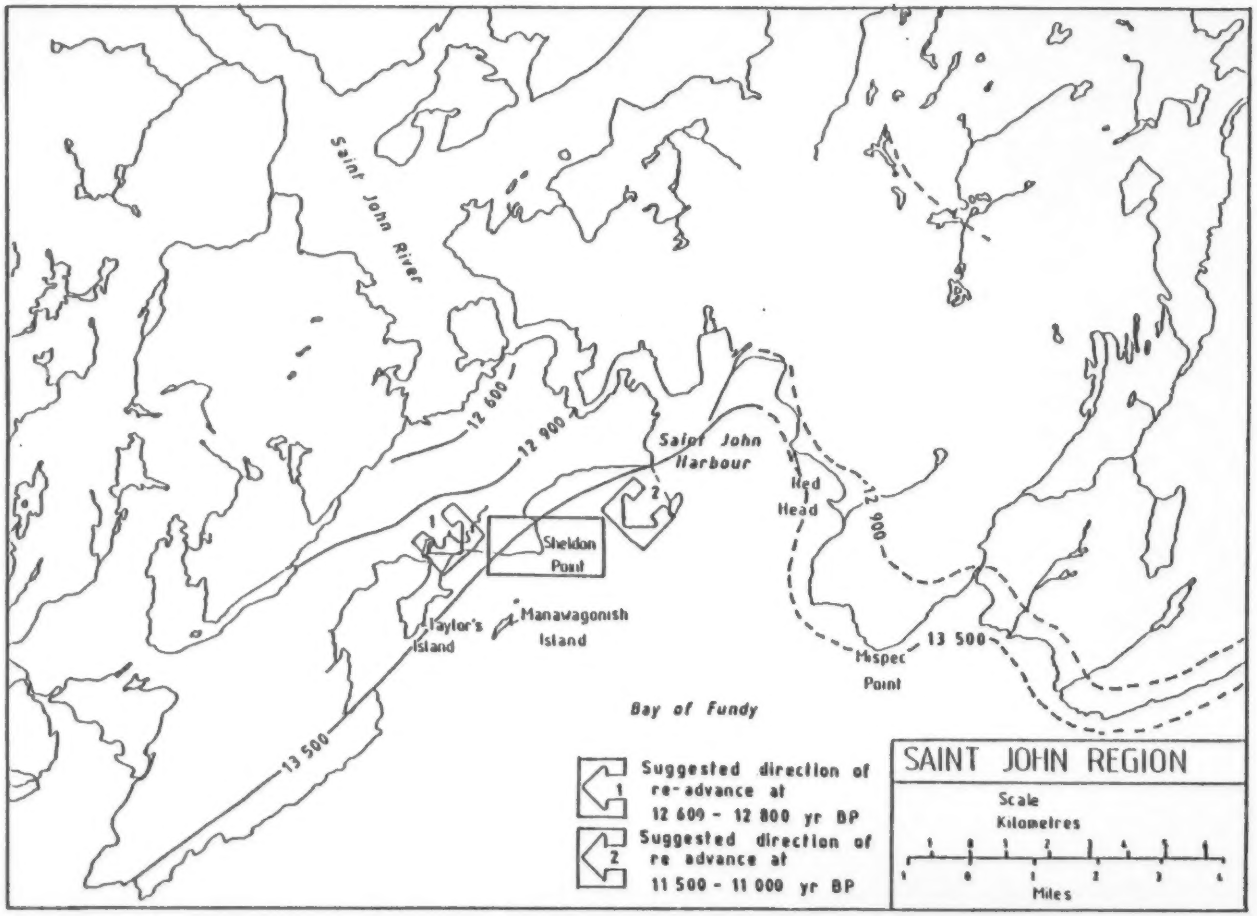


Figure 5.4. Location of glacial positions in the Saint John region during the late Wisconsian period.

The macrofossil data for the Bay of Fundy-Gulf of Maine region combined with the stratigraphy of Sheldon Point indicates that there are similarities in climatic regimes between the east coast of Canada, Great Lakes region, Greenland, and Europe. This would support the hypothesis suggested by Ruddiman and M^{c}Intyre (1981) for the shift in the polar front southward over the North Atlantic as a controlling mechanism for late glacial climate.

The Sheldon Point moraine is a glaciomarine end moraine. There is some indication that the Sheldon Point moraine may be used as a basis for a model for the Scotian Shelf moraine complex. There are many similarities between this moraine and the temperate tidewater moraines described by Powell (1981) for the west coast of North America. This suggests that the east coast of Canada may have had a temperate climate during the late Wisconsinan glaciation. Furthermore, the similarities between the Prairies and Great Lakes regions suggest a temperate glacial environment for the offshore areas. This suggests that the polar model described by King and Fader (1986) may not be the most applicable model for the east coast offshore areas of Canada.

Appendix 1

Complete list of sources for shell histogram for the Bay of Fundy-Gulf of Maine region

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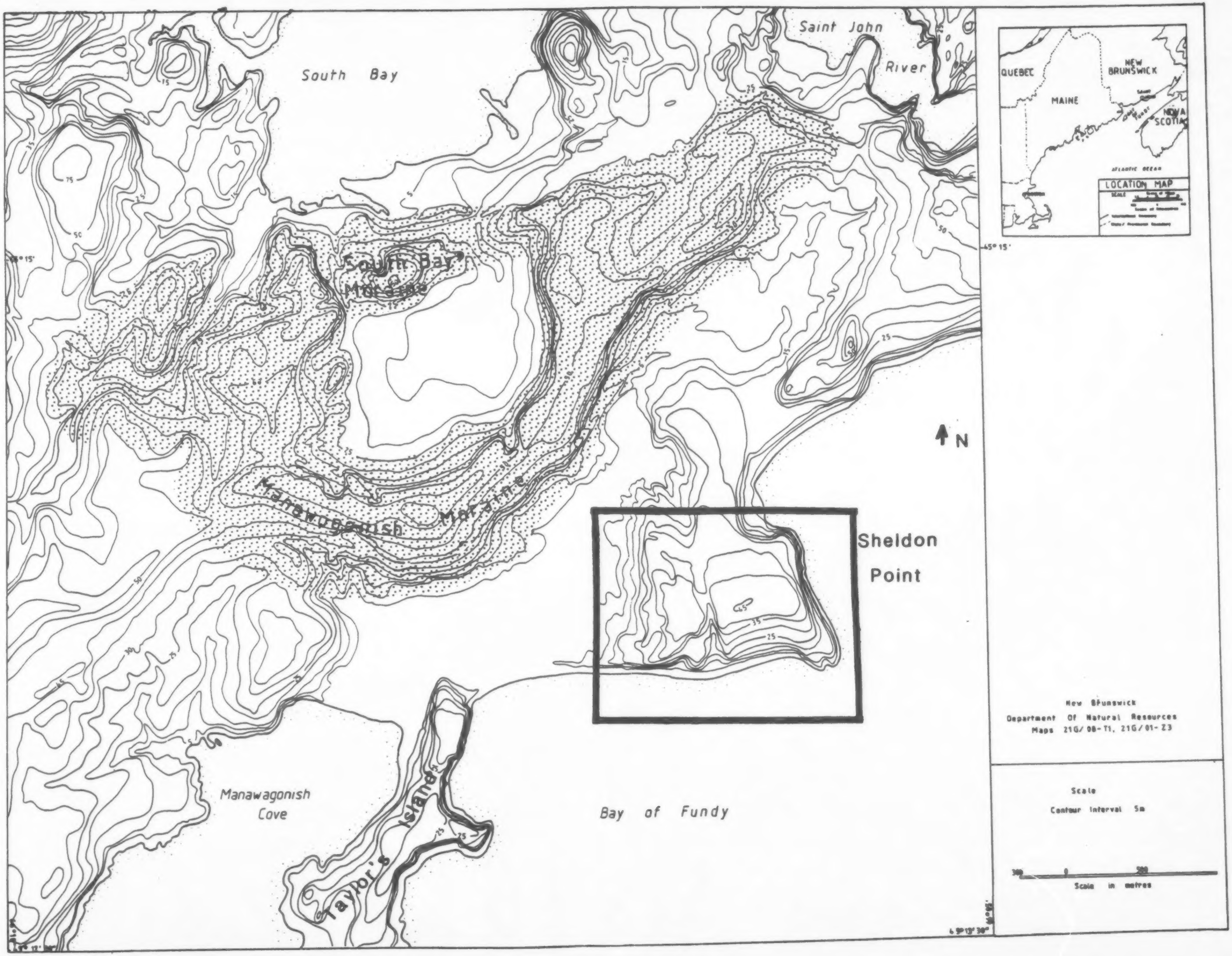

Figure 1.6. Map of west Saint John showing local morphology.